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ENGINEERING

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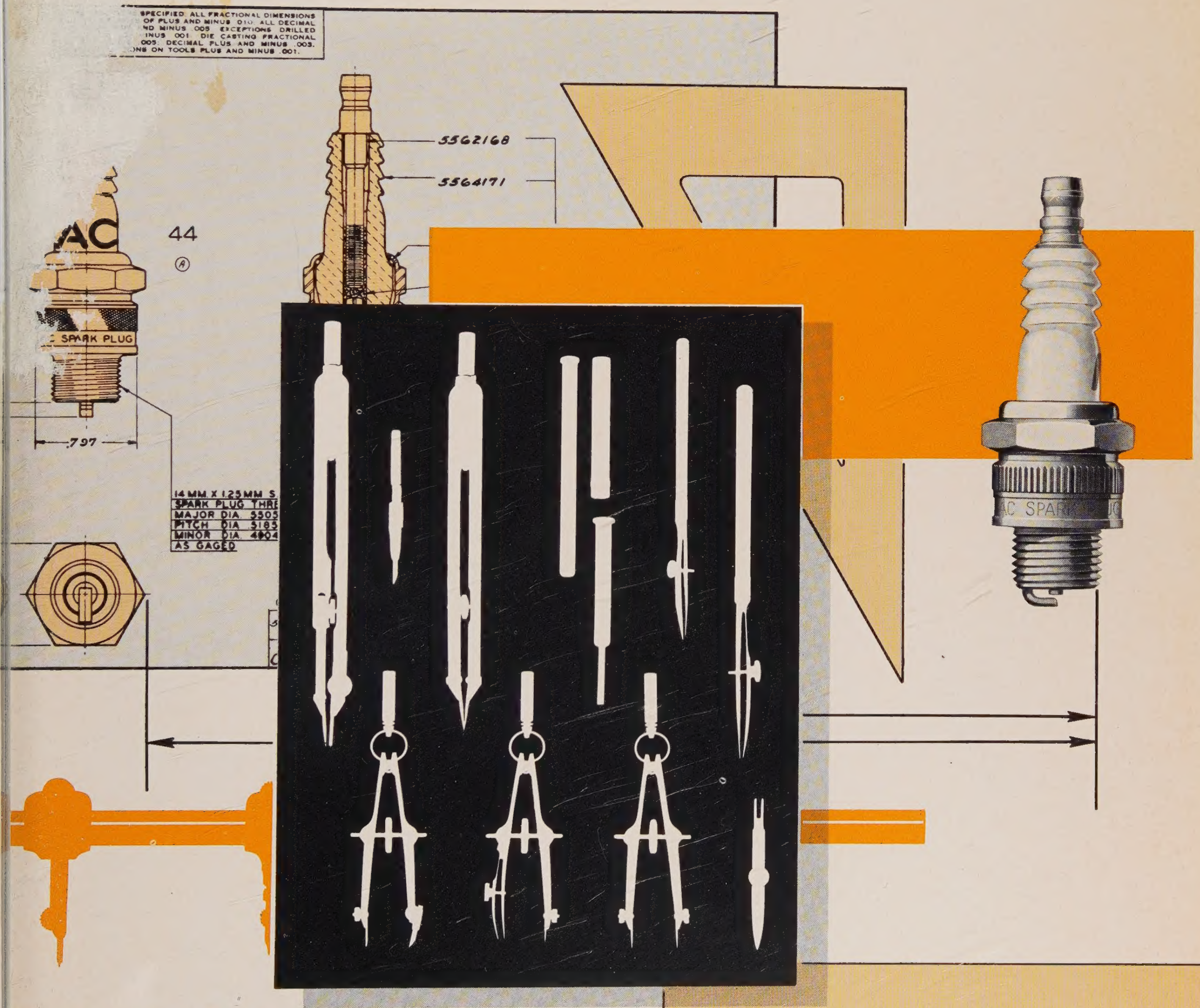
JOURNAL

for educators in the fields of engineering and allied sciences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DRAFTING — ENGINEERING'S UNIVERSAL LANGUAGE

On the Importance of Drafting in Engineering Development

Drafting is probably the engineer's most important form of communication. Just as picture writing, the first form of written communication, was used to express thoughts and records, so do engineers working with graphics mold intangible ideas and theories into tangible goods and products. Yet, there is a tendency in present engineering education to minimize the importance of drafting.

In applying for their first job after graduation, the majority of young engineers express a definite preference for experimental and testing work rather than for design. To them, design is associated with the drawing board, and they have been led to believe that work on a drawing board is of a menial nature, perhaps all right for a tradesman, but certainly beneath the dignity of a graduate engineer.

We have found, however, that these same young engineers, after two or three years in experimental or test activities, usually request a transfer to design work. They have learned by actual experience that the real creative engineering is done in the drafting room and that there must be a design before there can be a test or experimental program. They have discovered that drafting has a vital, dual function in the engineering organization:

(a) As a means of communication whereby ideas can be presented to others quickly and vividly

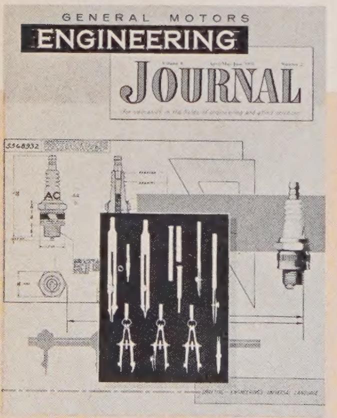
(b) As a tool whereby these ideas may be developed and expanded by graphical methods.

As with any language, skill can be obtained only by practice and certainly a few months of minimum drafting training received in college cannot be considered adequate practice for mastering such a vital skill. Consequently, young engineers should not only expect, but should seek several years of full-time design work.

It has been our experience that the most valuable men in an engineering development group are those whose broad background in designing permits them to follow a project from the initial freehand sketch to the finished prototype. Men of initiative and vision who have the ability to draw a good working layout, draw or supervise the drawing of the details, check the finished drawings, and then follow the parts in the shop through the assembly and testing phases are the type of "all-around" engineers constantly being sought to fill positions of higher responsibility.

As demonstrated by engineers of this type, drafting is by no means losing its place as an engineering tool.

Charles A. Chayne,
Vice President in Charge
of Engineering Staff



THE COVER

The competent engineer uses three languages—verbal, mathematical and graphical. His assignments sometimes dictate that he use one, or perhaps two, of these languages more often than another. Yet, all three must be at his command. For the engineer visualizes the forces of nature, he creates in his mind a product or process, and finally he must communicate his thoughts to others. The choice of his means of communication may be determined not by his preference but by the subject matter or by the recipient of the information.

In this issue's cover design by artist Richard P. Renius, the engineer's knowledge and use of graphical language is symbolized by a product assembly drawing, some drafting tools used for making the drawing, and the final product.

A knowledge of graphical expression is equally important whether the engineer engages in some of the drafting functions himself, or whether he supervises them in the work of others.

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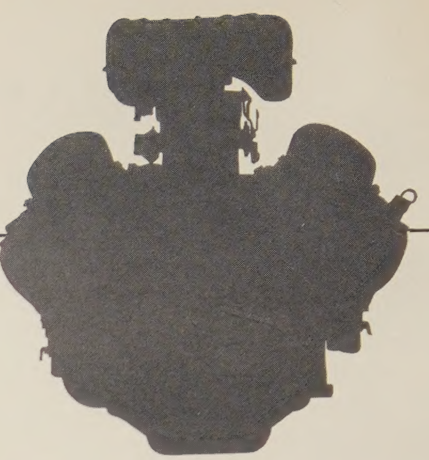
The Development and Use of a Modified V-8 Engine for Student Experimentation



The senior level mechanical engineering laboratory at General Motors Institute is integrated with applied design courses for the purpose of providing an environment where engineering principles can be re-examined, applied to proposed designs projected at least five years into the future, and then tested to establish their probable performance in a future application. The laboratory offers support and assistance to the design courses by giving a student the opportunity to evaluate his own design. This, of course, requires that equipment be available to meet the needs of student investigations. In some cases, equipment must be modified to meet specific teaching objectives. Such was the case in the modification of a V-8 engine to a four-cylinder test engine for single-cylinder operation. The engine was modified to provide students the opportunity to test and evaluate combustion chambers of their own design. Modification of the engine was not without problems. The solution of the problems involved, however, provided a challenge to both the students and faculty members. The engine has been in use for about one year. The results to date show it to be a highly useful and rewarding teaching device.

THE OVERALL objective of the General Motors Institute mechanical engineering laboratory is to provide a student the opportunity to investigate an engineering problem experimentally. The problem selected is of such a nature that the student will not know the exact results in advance. Thus, he is required to evaluate, analyze, and interpret the test data.

In the laboratory, senior students and faculty members work as a team to investigate and experiment with problems that cannot be defined easily. As a result, a student is placed in the laboratory under the same circumstances and conditions found in a typical engineering department or experimental laboratory.

A student is required to select his own problem for investigation, plan the investigation, obtain the test data, and analyze the results.

Laboratory Integrated With Design Courses

The mechanical engineering laboratory at General Motors Institute is integrated with classroom design courses. These courses, especially those in automotive engine design and development, are based on design problems which allow a student to project his thinking and ideas at least five years into the future. This provides the student an environment similar to what might be encountered later in his engineering career.

The mechanical engineering laboratory offers support to the classroom design courses by providing the student with valid data pertinent to his design problem and assists him by providing the opportunity to evaluate his own design, within limits. In the laboratory, therefore, a student is guided toward a broad investigation of a problem which he believes may be of direct value to his classroom design course work.

Engine Modified to Meet Specific Teaching Objectives

Equipment for such a laboratory program must necessarily be developed to meet the specific needs of design problems under study. In some cases, existing equipment must be modified, or new equipment and tools designed to meet the needs of a particular investigation.

An example of such a procedure can be illustrated by the modification of a Chevrolet V-8 engine to a four cylinder engine in which only one cylinder under test is fired. It was intended to use this engine for the study of combustion chamber size and configuration, valve timing and duration, spark advance, air-fuel ratios, and combustion cycles.

The objective was to provide an engine which a student could use to obtain current and valid data for application to the design of a future power plant and, also, to provide a student the opportunity to test and obtain performance information on prototype components for his engine of the future. In this way, for example, a student could evaluate his own combustion chamber design from the viewpoint of peak pressure, rate of pressure rise, octane requirements, idle characteristics, fuel consumption, and power output.

To meet this objective the V-8 engine had to be modified to:

- Operate with a full-size cylinder dimension and configuration on a small dynamometer
- Facilitate the installation of experimental combustion chambers with minimum difficulty in terms of construction, assembly, and disassembly
- Make possible the operation of any one of four different combustion chambers for test purposes, as desired, during a single laboratory period.

Before the modified V-8 engine could be used in the laboratory certain major problems had to be solved. First of all, removal of the four middle pistons and connecting rods from the engine created an interesting engine balancing problem. The unbalanced forces resulting from the removal of the four pistons and rods had to be determined in order to calculate the crankshaft counterweights required. This particular phase of the modification was assigned to three students as a laboratory project[1]. Other major problems dealt with the development of a method for making the student-designed combustion chambers; the development of a fuel system to supply fuel to any one of the four cylinders under test; and the installation of pressure transducers to pick up the variable cylinder pressures.

Modified Engine Stimulates Student Interest

The modified V-8 engine has been in use for approximately one year. The results so far have indicated it to be a

By **STEVE CENKO**
and **ELWOOD K. HARRIS**
General Motors Institute

Unique engine allows students to test and evaluate their own combustion chamber designs

stimulant to the creativity process of a student, in addition to an education for both the faculty and students. Operating an engine having a special combustion chamber of a completely different type, whose performance is unknown, has literally ignited the interest of students and faculty alike.

Sometimes, unexpected events occur during a laboratory period. For example, there are two and sometimes three different pressure-time curves occurring in sequence on the oscilloscope. When this happens the observers immediately try to establish what factors in engine operation tended to make one of the traces predominant. (For example, was it engine temperature or air-fuel ratio?)

Thus, such increased interest has promoted greater activity on the part of the students. The result is a better understanding of the various factors affecting the operation of a piston engine and a general recognition of the possibilities of power plants for the future.

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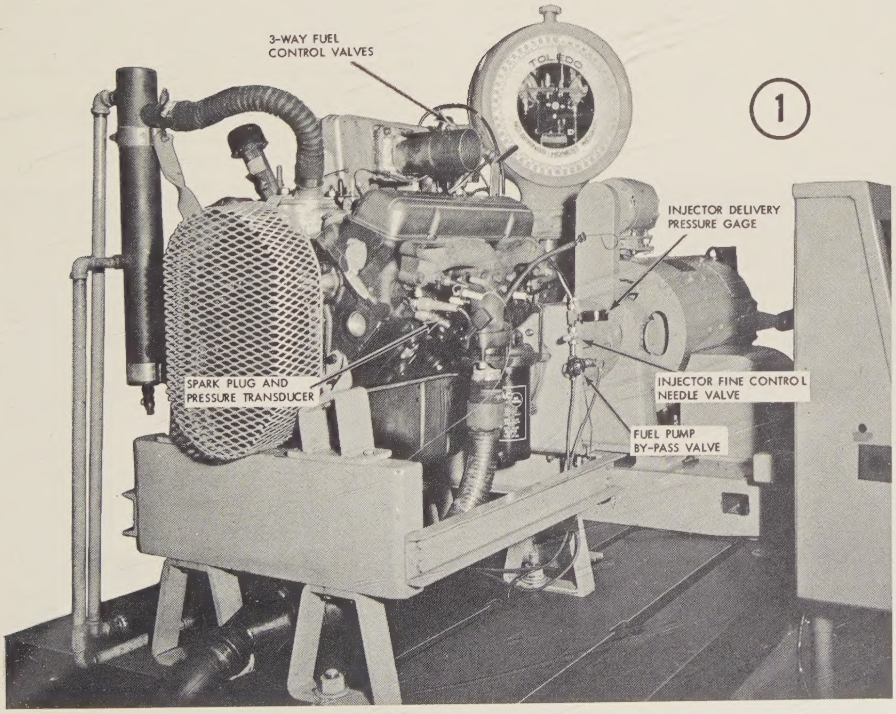
Some Features of the Modified V-8 Engine


3-WAY FUEL CONTROL VALVES
①
INJECTOR DELIVERY PRESSURE GAGE
SPARK PLUG AND PRESSURE TRANSDUCER
INJECTOR FINE CONTROL NEEDLE VALVE
FUEL PUMP BY-PASS VALVE

The major problems involved in modifying the Chevrolet V-8 engine to a four cylinder test engine (Fig. 1) for student use concerned rebalancing the engine after removal of the piston and rod assemblies from the four middle cylinders; fabrication of a fuel and air supply system; development of a means for installing pressure transducers to indicate the variable pressures within the combustion chambers; and the development of an inexpensive and relatively simple means for fabricating a student-designed combustion chamber.

The modified V-8 engine is operated with a manual spark advance, as is common with experimental engines. An ordinary timing light is used to establish the degree of spark advance. Establishment of timing marks on a dual beam oscilloscope is accomplished through the installation of special bolts in the flywheel which activate a magnetic pickup. These pulses are impressed on the sweep circuit of the lower beam and indicate 60° before top center, 60° after top center, and top dead center. This method can be adapted easily to other arrangements.

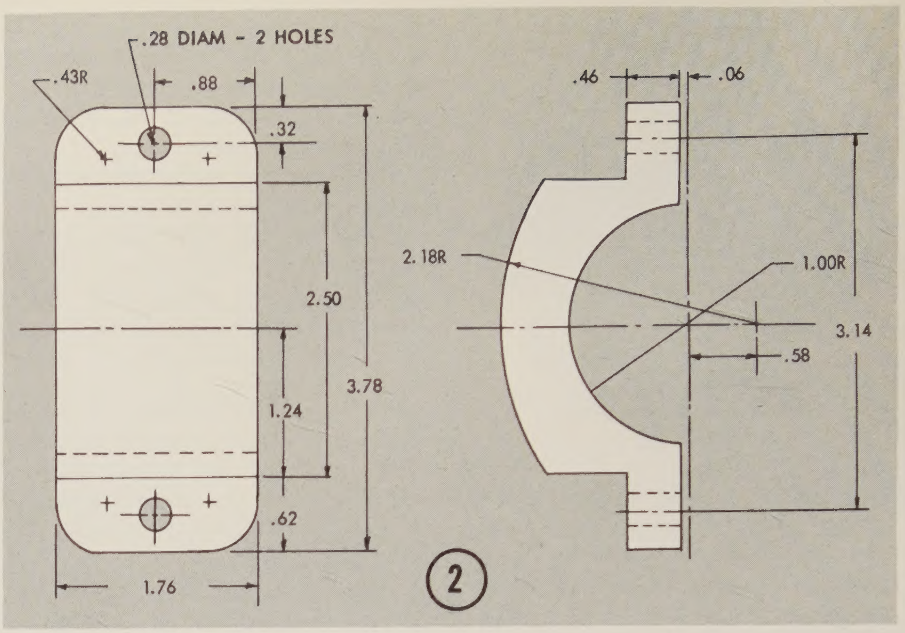
The water supply is controlled manually to give an accurate control of water temperature.

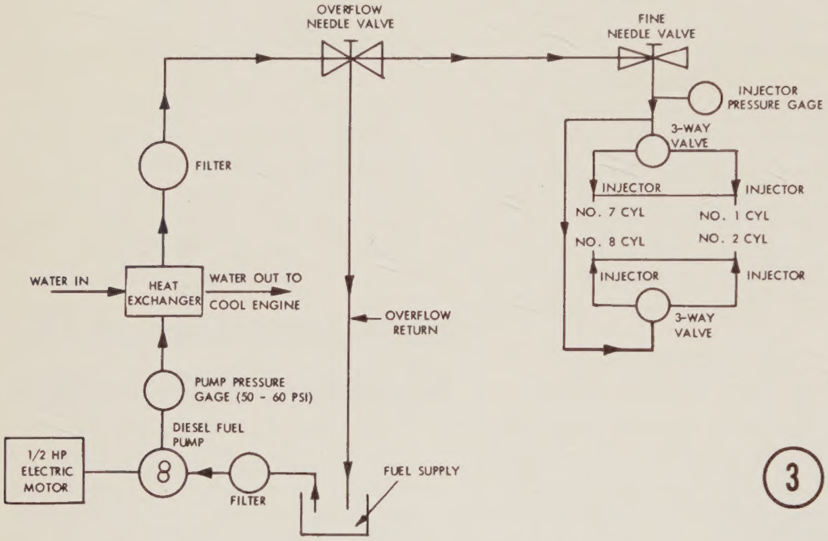
To rebalance the engine after the removal of the four middle piston and rod assemblies, counterweights of 2.65 lb each (Fig. 2) are mounted on the crank pins of cylinders three, four, five, and six. To minimize oil leakage between the counterweights and crank pin, the connecting rod lubricating passages in the crankshaft are plugged with lead shot.

Since the counterweights have been used no serious vibration problems have occurred, even though heavier-than-standard pistons have been used in the engine. Normally, the engine is operated at a speed below 2,000 rpm. Experience has indicated that operation at the maximum torque position is of more value for combustion studies than trying to obtain maximum power[2]. There is no reason, however, why maximum power, requiring increased engine speed, cannot be used or tested.

The fuel and air supply system (Fig. 3) for the modified V-8 engine is basically a standard Chevrolet fuel injection system. Fuel is supplied from a safety can through an external pump. The fuel is circulated through two filters (one in the intake line, the other in the pressure line) and a heat exchanger, to prevent vapor lock. It is then directed to a central manifold. A series of valves direct the fuel from the manifold to any one of the four operating cylinders. With this fuel system it has been possible to establish the fuel supply at minimum rate or leanest condition to obtain maximum torque[3].

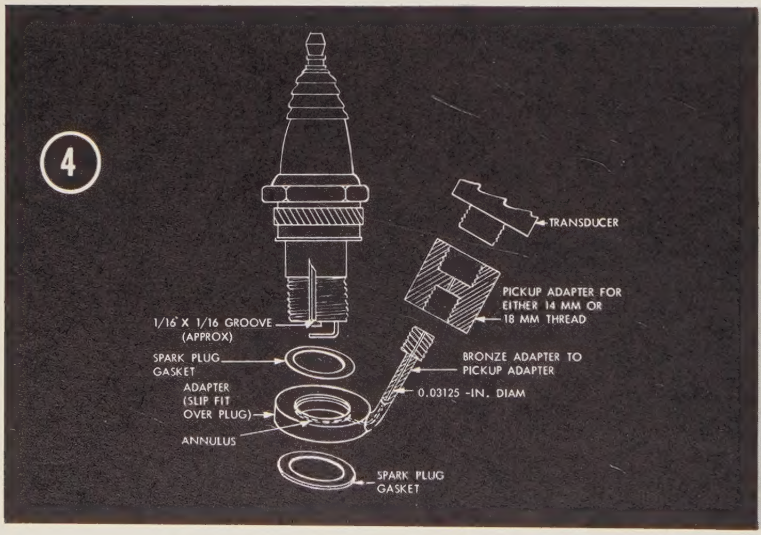
In the original conception of the modified engine, extra openings into the combustion chamber were provided on the outside corners of the two cylinder heads to allow for the installation of a pressure transducer. Upon running the engine, however, it was found that these openings interfered with the normal cooling pattern of the cylinder head, and thereby proved objectionable. Many schemes for picking up the combustion chamber pressure have been tried and found to be inadequate. The device currently used (Fig. 4) is simple and gives excellent results. The device consists of an adapter ring that slips over a standard long-shank spark plug which has a 1/16-in. by 1/16-in. groove ground through the threads. Cylinder pressure travels through this groove to a collecting annulus in the adapter ring and then through a brazed-on tube (having a 0.03125-in. inside diameter) to the adapter fitting for the pressure transducer.

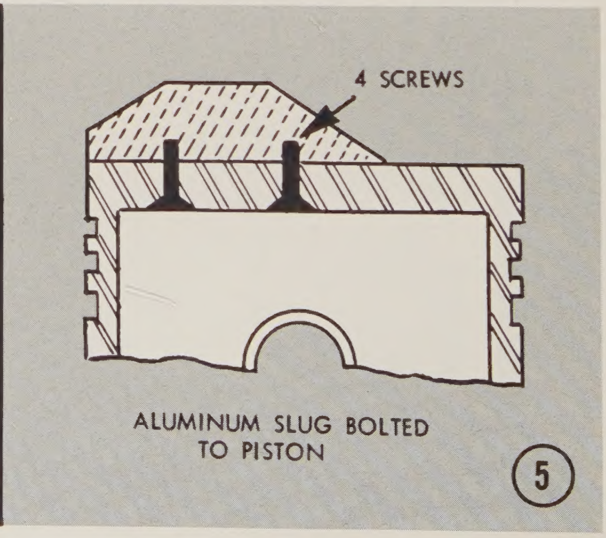


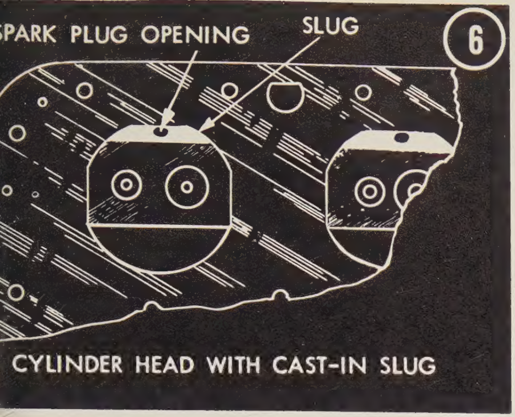


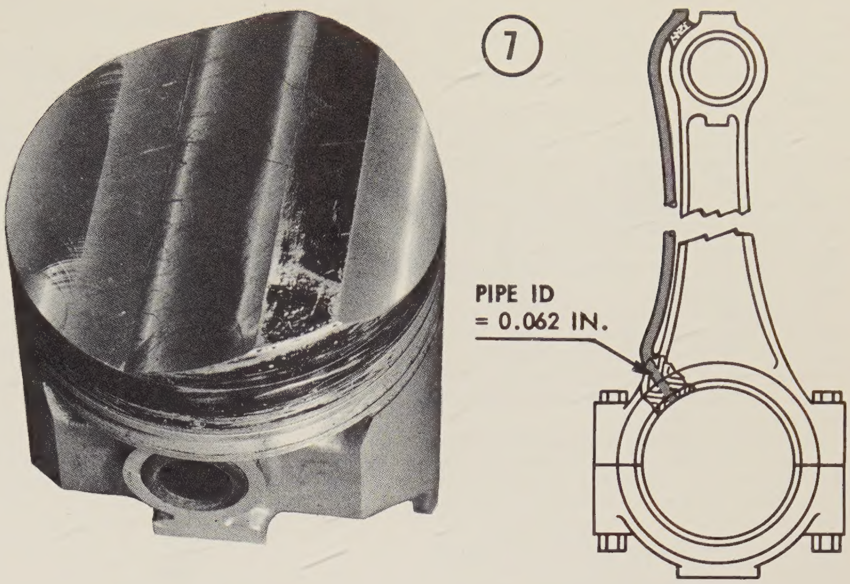
Since the modified engine has been in operation, several methods have been used to create the combustion chambers designed by students. The students design the combustion chambers to provide a compression ratio similar to that expected for their engines of the future. The compression ratio has been approximately 12 to 1.

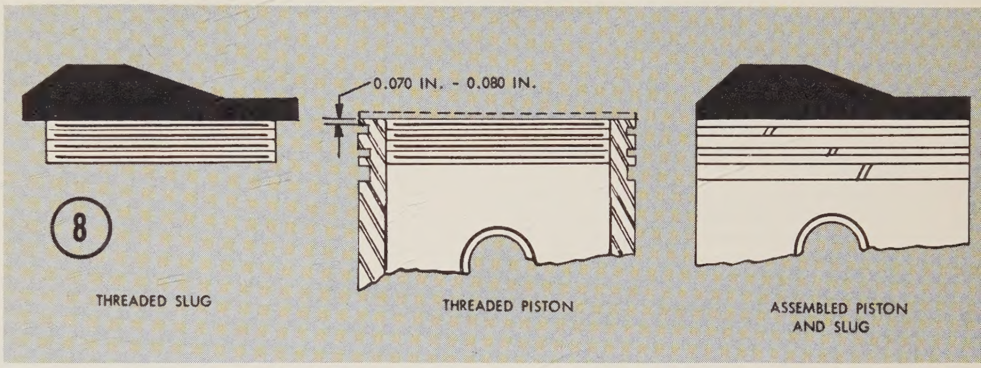
One of the first methods used for creating the


4
TRANSDUCER
PICKUP ADAPTER FOR EITHER 14 MM OR 18 MM THREAD
1/16 X 1/16 GROOVE (APPROX)
SPARK PLUG GASKET
BRONZE ADAPTER TO PICKUP ADAPTER
ADAPTER (SLIP FIT OVER PLUG)
0.03125 -IN. DIAM
ANNULUS
SPARK PLUG GASKET









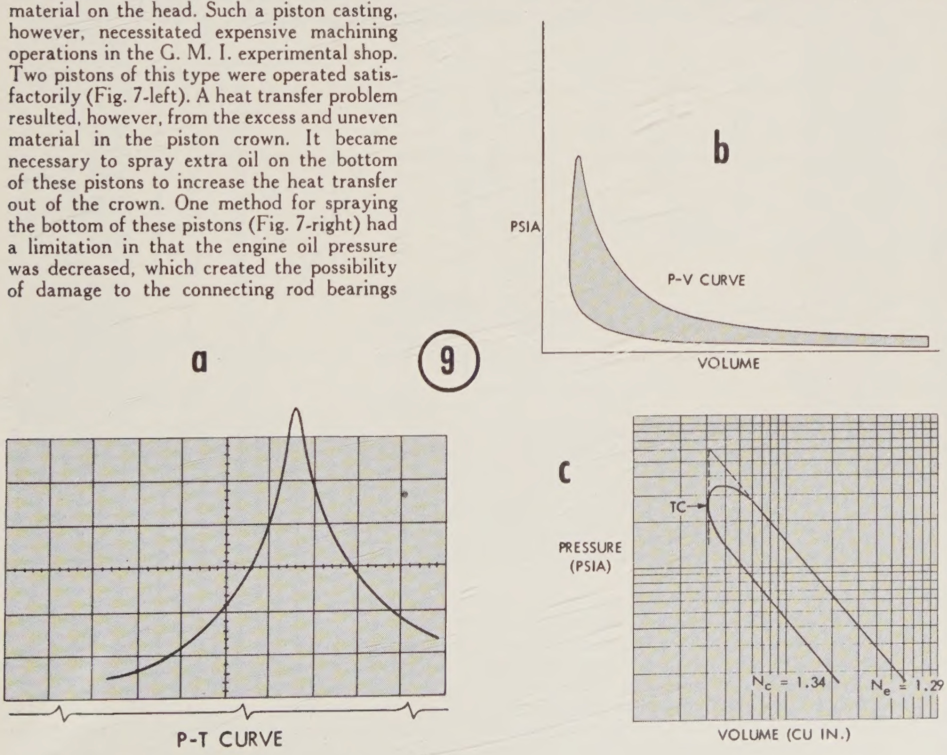
combustion chambers consisted of bolting a machined slug of aluminum to the top of the piston (Fig. 5). The slug was of sufficient size to increase the compression ratio to the desired value. In spite of the obvious heat transfer problems, these pistons operated satisfactorily.

An alternate method for increasing compression ratio was to change the combustion chamber configuration by pouring molten aluminum into the cylinder head portion of the chamber (Fig. 6). The shape of the casting was controlled by a plaster dam. The casting was anchored to the head by two bolts. This method proved satisfactory for a compression ratio of 10.5 to 1. After the engine had been operated for a few minutes, however, the heat transfer coefficient decreased, and the aluminum disintegrated. To rectify this situation, a brass plate was brazed into the cylinder head to accomplish the same change in combustion chamber volume.

The next method for creating the student-designed combustion chambers was to obtain castings of the commercial piston with extra material on the head. Such a piston casting, however, necessitated expensive machining operations in the G. M. I. experimental shop. Two pistons of this type were operated satisfactorily (Fig. 7-left). A heat transfer problem resulted, however, from the excess and uneven material in the piston crown. It became necessary to spray extra oil on the bottom of these pistons to increase the heat transfer out of the crown. One method for spraying the bottom of these pistons (Fig. 7-right) had a limitation in that the engine oil pressure was decreased, which created the possibility of damage to the connecting rod bearings and crank pin. Experience indicated that the inside diameter of the tube running along the side of the connecting rod should not exceed 0.062 in.

The most promising method for creating the combustion chambers was an adaptation of the commercial piston. This method required cutting out the top of the original piston and machining threads on the inside of the remaining portion (Fig. 8). A corresponding aluminum casting was then machined with threads to fit. Thus, any shape could be machined into this new casting, which then became an integral part of the piston. Oil cooling was even more important with this type of piston because of poor heat transfer across the threads.

Student-designed combustion chamber configurations have been operated successfully in the modified engine at compression ratios of 10.5, 11.5, 12.5 and 13 to 1. The performance of these configurations has been compared directly to the original combustion chamber design of the engine, which operated at a compression ratio of 7.7 to 1. The comparison between these combustion chambers, purposely designed to be completely unorthodox, provided an interesting study for the



students. Figs. 9a, 9b, and 9c show typical pressure-time, pressure-volume, and log-log pressure-volume diagrams, respectively, obtained with the modified 12.5 to 1 compression ratio engine running with a student-designed combustion chamber.

The log-log pressure volume plot (Fig. 9c) illustrates the deviation of the *N* value from ideal to actual of the compression and expansion curves, as well as the start and end of combustion.

Various other methods of developing combustion chambers were tried. Test results, however, indicated that each combustion chamber to be tested needed an experimental analysis as to volume distribution.

The analysis used was based on the Taub method[4]. This method permits a combustion chamber to be evaluated as to whether it is rough or smooth during operation. The Taub method also correlates with the rate of pressure rise during combustion.

The volume distribution for each experimental combustion chamber was established by first obtaining an epoxy resin casting of the clearance volume (Fig. 10). A spherical sectioning machine was then used to cut away the casting. This machine consisted of a small turn table with a swinging cutting arm. The cut, which begins at the proposed spark plug location, was made with a spherical motion, since the flame front of the combustion process moves as a sphere. As each cut was made the volume of the casting removed was noted, along with the increment of travel of the cutter. This increment is equal to the increment of flame travel. The data were then plotted and compared to a standard, or "bogey," curve. Fig. 10 (right) shows a typical volume distribution curve for one of the student-designed combustion chambers.

Another method of performing the Taub analysis is to section the combustion chamber graphically.

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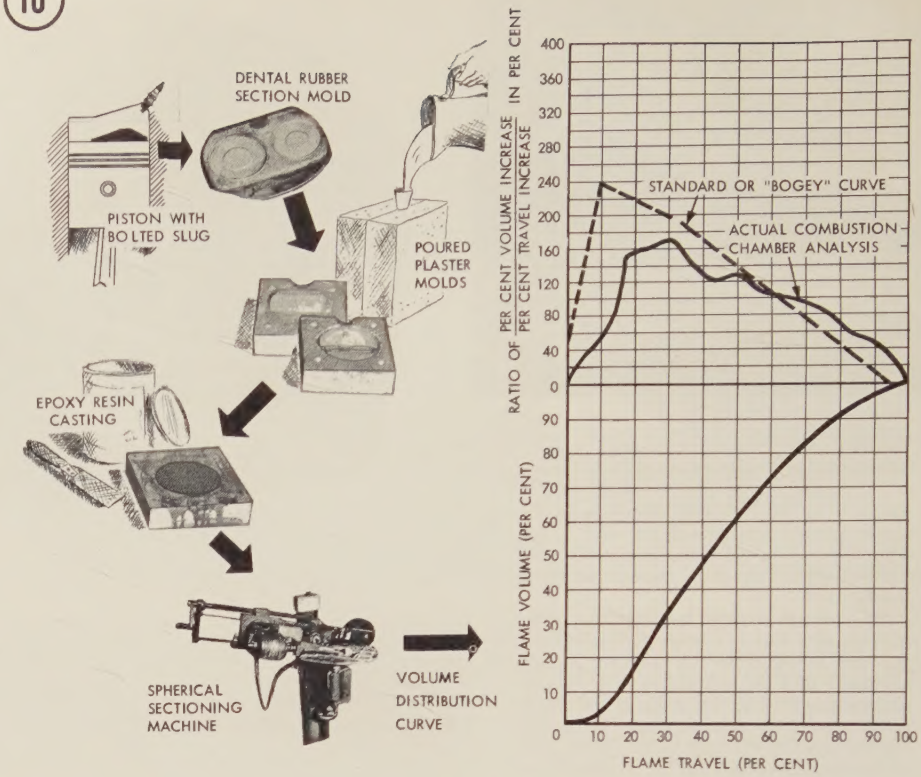
DENTAL RUBBER SECTION MOLD
PISTON WITH BOLTED SLUG
POURED PLASTER MOLDS
EPOXY RESIN CASTING
SPHERICAL SECTIONING MACHINE
VOLUME DISTRIBUTION CURVE
RATIO OF PER CENT VOLUME INCREASE / PER CENT TRAVEL INCREASE IN PER CENT
400
360
320
280
240
200
160
120
80
40
0
STANDARD OR "BOGEY" CURVE
ACTUAL COMBUSTION CHAMBER ANALYSIS
FLAME VOLUME (PER CENT)
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
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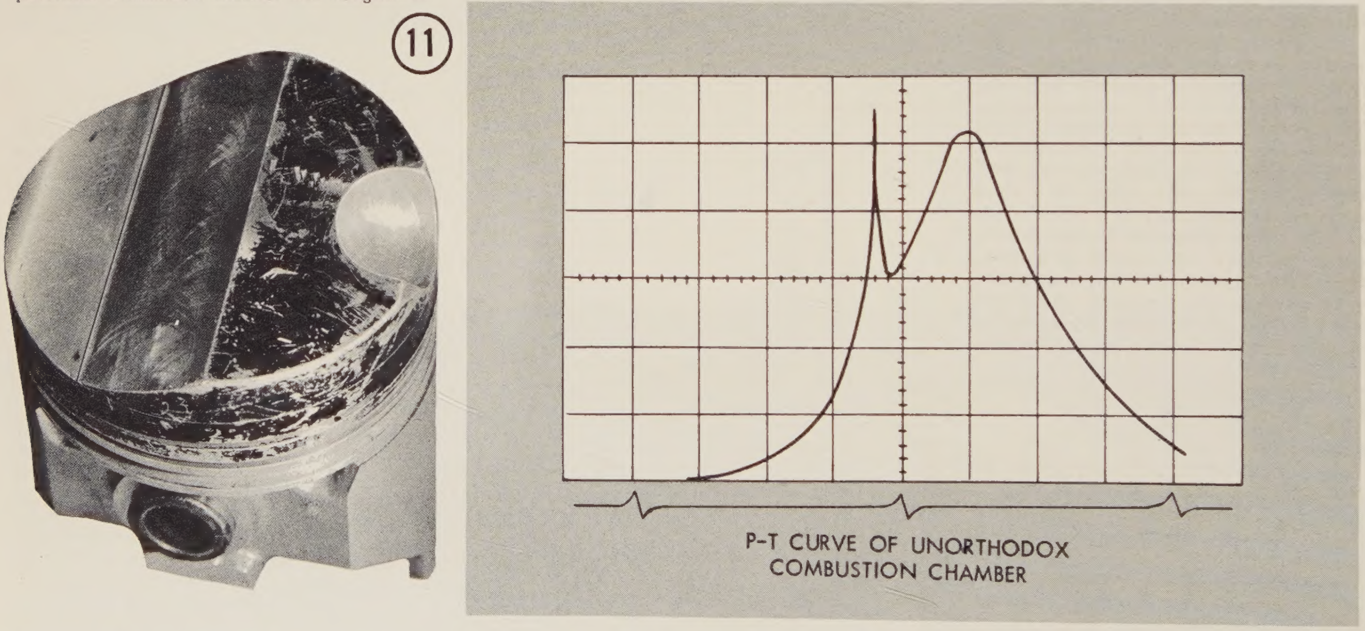
FLAME TRAVEL (PER CENT)

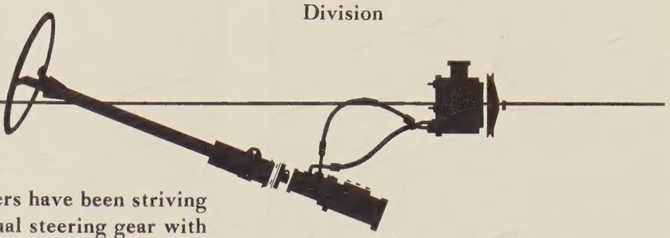
One of the more interesting experiments with the modified engine occurred while testing a completely unorthodox combustion chamber configuration at a compression ratio of 13 to 1. This particular combustion chamber was designed to concentrate the combustible mixture in a spherical pocket near the spark plug (Fig. 11-left). Limitations in the chamber casting, however, did not allow this design objective to be completely achieved. When the combustion chamber was tested, a peculiar shape was noted on the pressure-time diagram (Fig. 11-right). The pressure built up rapidly during combustion in the spherical pocket and diminished slightly during the transition into the squish area. While the engine was running, this peculiar "hook" was noticed and various changes in engine operation were tried to see if the characteristic shape could be changed. After about one hour of operation the pressure-time diagram started to change, causing the observers to believe that the instrumentation had deteriorated. Upon disassembly of the engine, however, it was found that a portion of the piston crown had actually burned away during operation. This change in combustion chamber volume distribution had a definite effect upon the shape of the pressure-time curve, and served as a good illustration to the students that the pressure-time curve is sensitive to the combustion chamber itself.

⑪


P-T CURVE OF UNORTHODOX COMBUSTION CHAMBER

Improving Product Design: Development of the Rotary Valve Power Steering Gear

By **BLAIR THOMPSON**
Saginaw Steering Gear Division



Since the advent of power steering systems for automobiles, engineers have been striving for a power steering unit which incorporates the response of a manual steering gear with the smoothness and lightness desired in a power steering gear. This challenge finally has been met by a rotary valve integral power steering gear developed by Saginaw Steering Gear Division engineers. This new gear provides hydraulic valve response in less than one degree of handwheel movement with a down-the-road effort of slightly less than one pound on the rim of the handwheel, while retaining a desirable amount of road feel. Also, the new gear provides a maximum parking effort of three pounds.

Some design results: faster hydraulic response, fewer parts, shorter length

MANY of the outstanding engineering contributions in modern automobiles have centered about improved handling and ride comfort. Perhaps the most influential component affecting handling and ride is the steering system.

A good steering system should provide a safe means for guiding the vehicle with a minimum of driving effort. This should be accomplished without sacrificing road feel and without vibrations at the handwheel caused by forces reacting against the front wheels due to rough roads.

The basic components of the steering system are pivoted front wheels, a steering linkage, a steering gear, and a steering wheel[1] (Fig. 1). Steering effort is transmitted through the steering wheel to the steering gear, which actuates the steering linkage to turn the pivoted front wheels. It is the design of the steering gear which provides the correct mechanical advantage for easy steering.

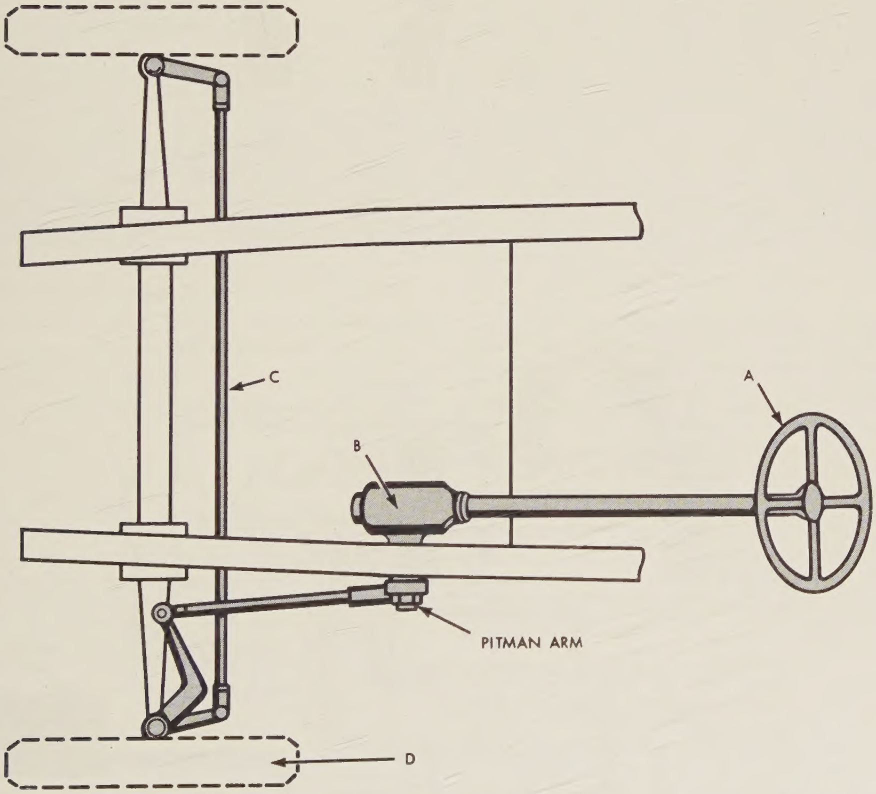


Fig. 1—A typical automobile steering system consists basically of the steering wheel *A*, the steering gear *B*, the steering linkage *C*, and the pivoted front wheels *D*. The steering wheel receives input from the driver which is transmitted to the steering gear. Reduction gears are employed to ease the effort of steering. The steering gear moves the linkage, which turns the front wheels in the desired direction. Several designs of these components are used in different vehicles to meet specific design and functional criteria. Most early steering systems used an application of the worm and worm-wheel principle in steering gears.

Early Steering Gear Developments

At the turn of the century, automotive vehicles began to mature from the horseless carriage to the automobile. Chain drives were replaced by propeller shafts. The power, size, and weight of vehicles increased. Tires became larger and required lower inflation pressures[2]. These developments added to the difficulty of steering the vehicle with the tiller mechanisms of that period. As a result steering gears, or reducing gears, were developed which were inserted between the hands of the driver and the front wheels of the car.

Most early steering gears were comprised of a gear box mounted on the frame of the vehicle, housing a driven gear and a drive gear. The drive gear was on the end of a steering shaft, which extended into the driver's compartment and was fitted with a steering wheel. The driven gear was connected to an arm (known as the steering arm, drop arm, or pitman arm) which connected, in turn, to the steering linkage.

Since the introduction of the first steering gears at the turn of the century, many improvements have been made and introduced, including: the cam and lever gear; the roller tooth gear; the

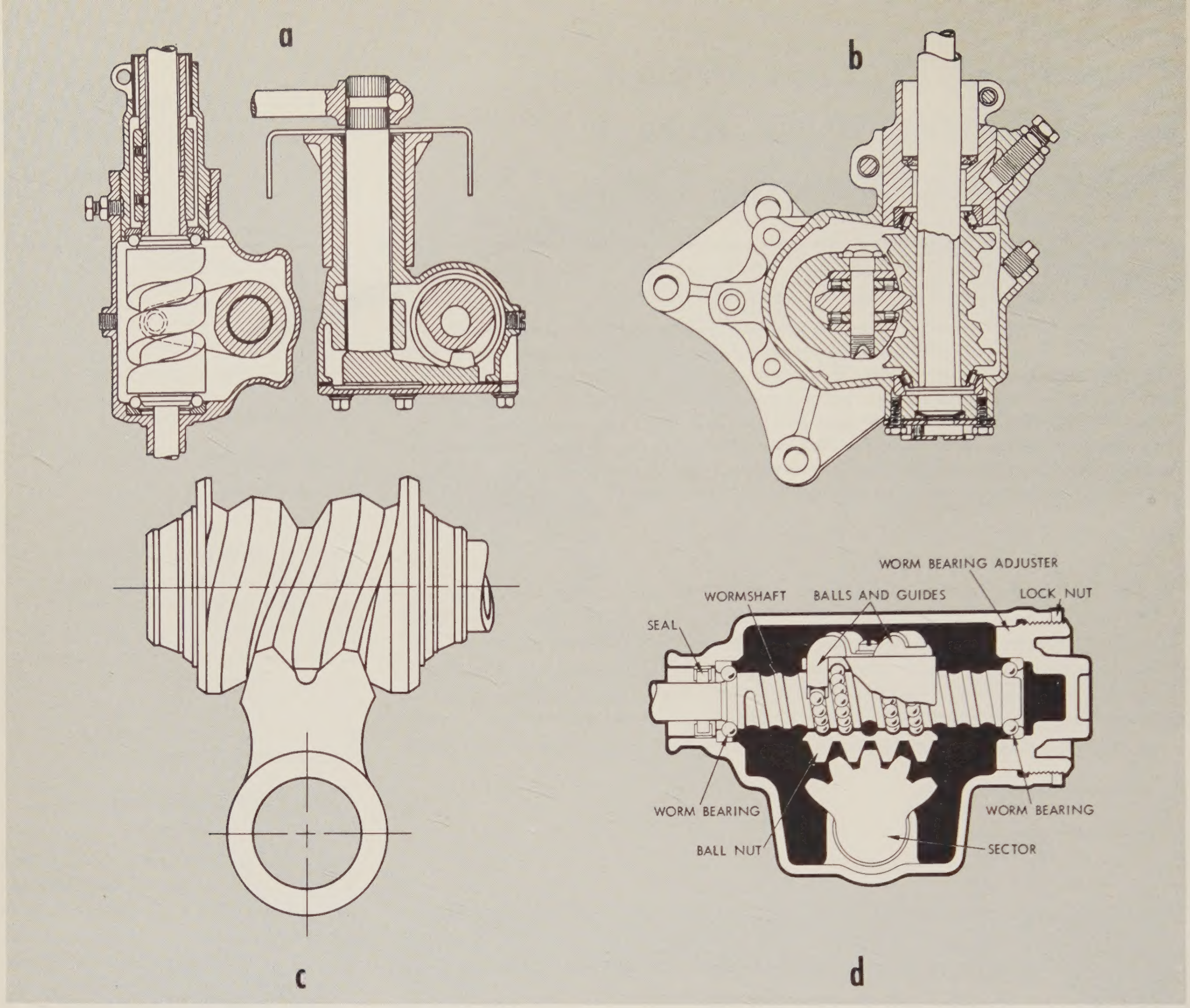
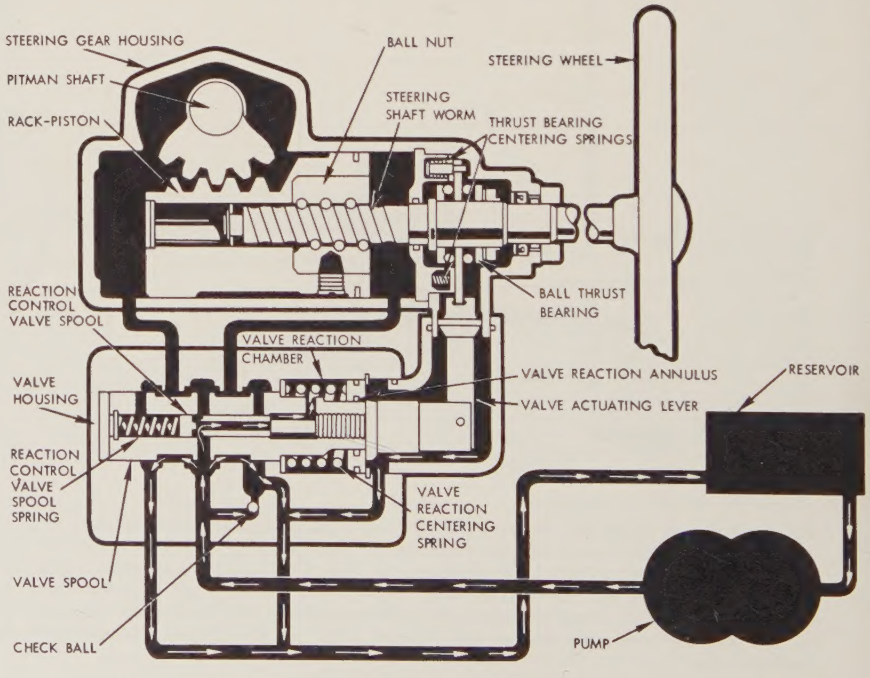


Fig. 2—Introduced in 1923, the cam and lever steering gear (a) applied steering effort through a coarse-pitch worm groove to a pin on the outer end of a lever. The lever applied torque to a rod which transmitted the power to the steering gear arm. Later, the roller tooth steering gear (b) substituted rolling for sliding contact in the steering gear. This reduced friction, and also the size of the gear box. The first worm sector steering gear (c) was introduced on trucks. It then appeared on most passenger cars, and was the basis for modern manual steering. The greater helix angle of the worm increased its efficiency over that of the worm and worm-wheel gear. The recirculating ball nut steering gear (d), which entered heavy production in 1941, was a reversion to the screw and nut type gear. This gear, however, contained recirculating balls between the nut and thread grooves which reduced friction greatly and increased the ease of steering.

worm and sector gear; and the recirculating ball-type steering gear (Fig. 2).

Power Steering First Used During War

Power steering, developed to decrease the effort required to steer the modern,



heavier automobile, contributes much to the safety of the car. Some early kinds of power steering involved the use of hydraulic cylinders on the steering linkages to provide power assist during steering. Most present models are integral units, with hydraulic power used to assist the movement of the steering gear.

The basic components of an integral, hydraulic power steering gear unit are the oil reservoir and pump, the hydraulic valving means, and the power cylinder, which holds the power rack, or piston. The pump supplies oil to the power cylinder through the valving means. The power cylinder is full of oil at all times and acts as a cushion to absorb road shocks. The valving means, however, directs high pressure oil to the desired side of the power cylinder, where it aids in moving the power rack, or piston, in the desired direction. The power rack is actuated manually by the steering wheel, which also actuates the valving means, thus providing power assist in moving the rack. The power rack connects to the pitman shaft, or steering arm, sector gear which actuates the steering linkage and the front wheels.

Prior to 1959, Saginaw Steering Gear Division manufactured a power steering gear which required only 4½ lb of handwheel effort for turning, while providing good "road feel." Engineers believed, however, that further reduction of steering effort was possible, while retaining sufficient road feel, and while reducing the size, weight, and number of parts of the gear. Research led to the development of a new valving means, incorporating a rotary valve, which enabled engineers to produce a new power steering gear having the desired improvements.

Fig. 3—The in-line hydraulic power steering gear assembly, manufactured by Saginaw Steering Gear Division from 1956 through 1958, contained a three way, open center, spool-type valve. Other components were a pump, an oil reservoir, and a double acting cylinder and piston. When the steering wheel was turned the first, imperceptible movement of the worm caused the valve actuating lever to move. The lever moved the valve spool axially, which affected the flow of oil through the valve directing high pressure oil to one side of the cylinder, which moved the piston in the other direction. The piston moved the power rack with it, which applied turning effort to the pitman shaft. Centering springs were provided on the worm thrust bearing and in the valve assembly to provide a feel of the road and satisfactory returnability. A valve reaction area also was provided in the valve assembly, so that a centering force in proportion to hydraulic pressure was provided.

Spool Type Valve Used in 1958 Steering Gear

The in-line hydraulic steering gear assembly (Fig. 3) manufactured by the Saginaw Steering Gear Division from 1956 through 1958 consisted of a recirculating ball nut and worm assembly, power rack, and pitman shaft sector gear, which constituted the steering gear portion of the gear. The gear also contained a hydraulic valve to control the flow of oil, and a double acting piston which was integral with the rack. The valve assembly was a three way, open center, spool-type valve. This valve was actuated by axial movement of the steering worm. The steering worm was connected to the steering shaft and steering wheel.

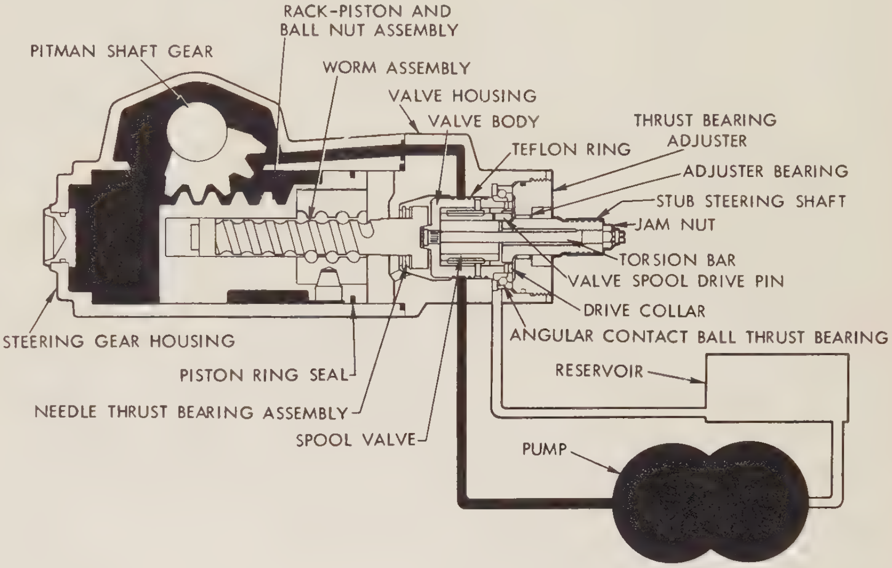


Fig. 4—The first design of a rotary valve steering gear assembly showed much similarity to the in-line gear (Fig. 3). The basic differences were that the first design of the newer valve functioned with rotary instead of axial motion, and that the placement of the new valve in relation to the other components was changed.

The valve body was constructed of four separate pieces, press-fitted, with the inner diameter finish-ground to fit the spool. Three rectangular section teflon rings circumvented the valve body and acted as annular seals for the pickup of pressure oil and oil for the lower cylinder (the side of the cylinder farthest from the valve). The upper cylinder (side of the cylinder nearest the valve) was fed by a hole drilled between the valve bore and the outer diameter of the valve body below the lower teflon annular seal. The return oil flowed through holes drilled in the valve spool, through the angular thrust bearing, and out the return hole in the valve housing.

The valve spool was driven by a pin, press-fitted into the stub steering shaft, which engaged a slot in the upper end of the valve spool. This kind of drive allowed for misalignment between the valve body and stub steering shaft, and prevented binding of the spool in the valve body, which was selectively fitted to a clearance of from 0.0004 in. to 0.0008 in.

The worm assembly was fixed in an endwise direction by thrust bearings located at the lower side of the shoulder and at the upper end of the valve assembly.

The centering means for the valve spool consisted of a torsion bar anchored at the bottom by splines to the valve body and to the stub steering shaft at the upper end by threads, plus a locking jam nut. A torsion bar was chosen as a centering means since it was simple and positive, and provided a centering force proportional to the angle of deflection.

The purpose of the threaded end of the torsion bar in the stub steering shaft was to provide a means of adjusting the neutral position of the bar to the hydraulic neutral center of the valve assembly. This adjustment was made by first deflecting the torsion bar to the right by means of the stub shaft to build 200 psi pressure, then by deflecting it to the left to build the same pressure, and finally by adjusting the position of the torsion bar relative to the stub shaft until the effort required to deflect the bar to the right and left to build 200 psi was equal, within commercial limits.

In case of hydraulic failure, manual steering was accomplished through a drive collar which engaged slots in the valve body and stub steering shaft. This collar transmitted manual power through the valve body. The worm (which in turn drove the rack and sector gear) was driven by the valve body where a tapered tongue and groove were forced together by the thrust bearing adjustment, eliminating lash at that point. The drive collar engaged after the stub steering shaft had rotated approximately six degrees to either side of the neutral position. During normal hydraulic operation, six degrees was the amount of rotation necessary for valving plus overtravel.

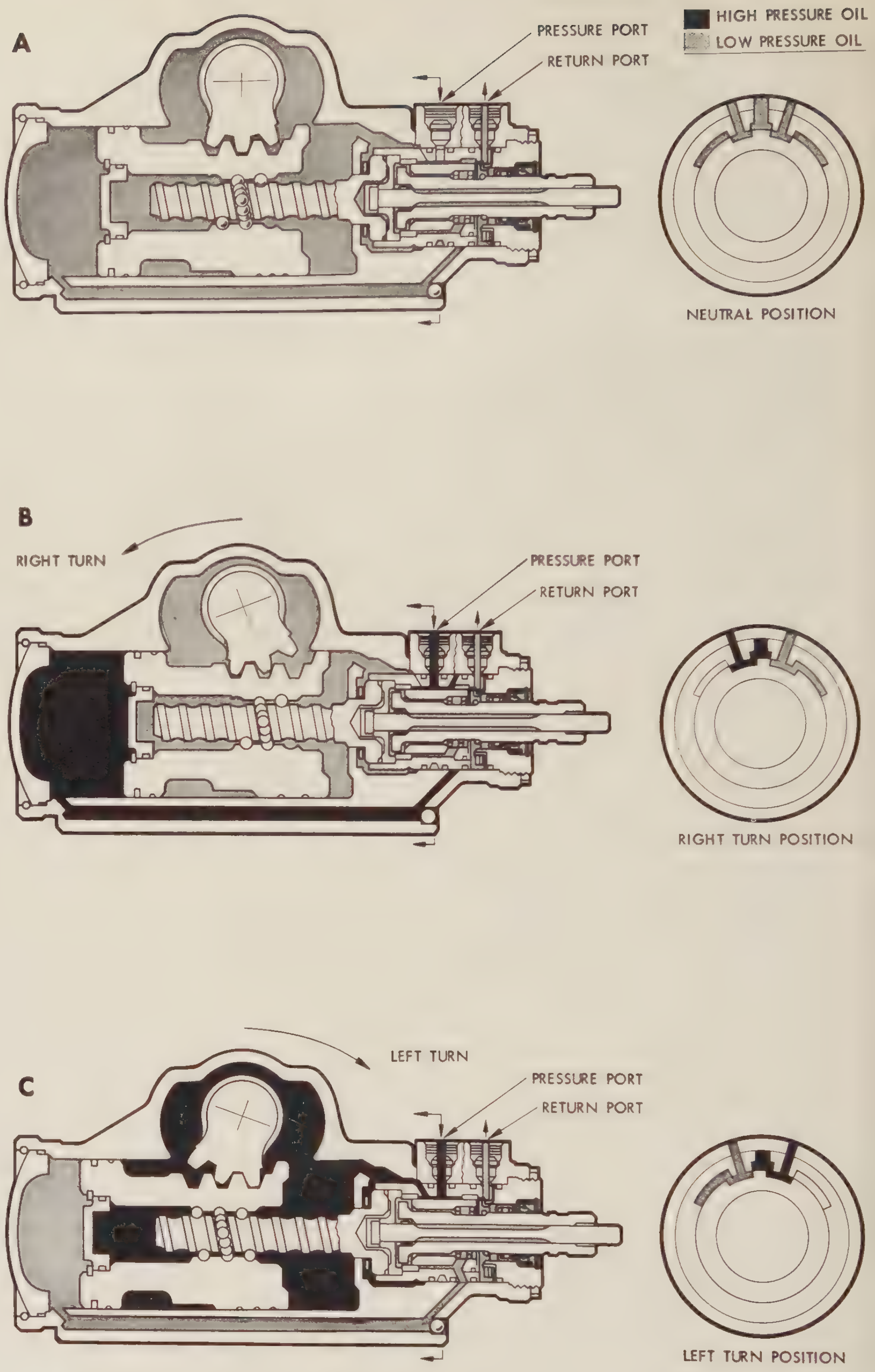


Fig. 5—Evaluation of the first design of the rotary valve steering gear assembly (Fig. 4) led to the final design which shortened the length of the gear by moving the location of the piston ring seal; combining the rack-piston and ball nut into one piece; and combining the steering gear housing and valve housing into one piece. The gear shown is the production model used in 1959 automobiles. Flow diagrams show the neutral *A*, right turn *B*, and left turn *C* positions of the gear. Accompanying cross section diagrams of the valve body and valve spool, cut perpendicular to the centerline of the gear, show the three positions of the valve. With the valve in the neutral position *A*, the valve gaps are open and oil flows freely through the valve and back to the pump with a minimum of pressure drop. During a right turn *B*, the valve spool is displaced clockwise within the valve body. This opens the right turn valve lands to pressure oil and the left turn valve lands to return oil. During left turn *C* the spool is displaced counterclockwise, opening the left turn lands to pressure oil and the right turn lands to return oil.

Although this design functioned very satisfactorily, further research revealed that changes could be made which would result in an even better steering gear assembly. From experience with steering gears, a set of objectives for new steering gear designs was established.

Previous Experience Sets Basic Design Criteria

The objectives established as design criteria for new power steering gear assemblies developed by Saginaw Steering Gear Division were as follows:

- Instantaneous hydraulic response
- Light steering effort without loss of proportional road feel
- Elimination of hydraulic transition feel
- Improved returnability
- Prevention of loss of on-center steering adjustments
- Reduced number of external oil seals
- Reduction of size, weight, and number of parts.

Hydraulic response refers to the amount of angular handwheel movement required to actuate the hydraulic valve to obtain a build-up of oil pressure in the power steering system.

Proportional road feel refers to a linear function between input and output forces.

Hydraulic transition may be described as a slight build-up followed by a slight drop in handwheel effort occurring at the point of valve actuation due to breakaway friction in the valve actuating mechanism.

Returnability refers to the ability of the steering system to return to a straight ahead position without assistance from the driver.

On-center steering adjustment refers to a mesh preload between the gear teeth and rack, which eliminates any lash with the steering gear in a straight ahead position.

Design Objectives Indicate Design Methods

Past experience in designing and manufacturing power steering gear assemblies aided in establishing the approach to use to meet the design objectives outlined for the new gear.

Quicker hydraulic response could be

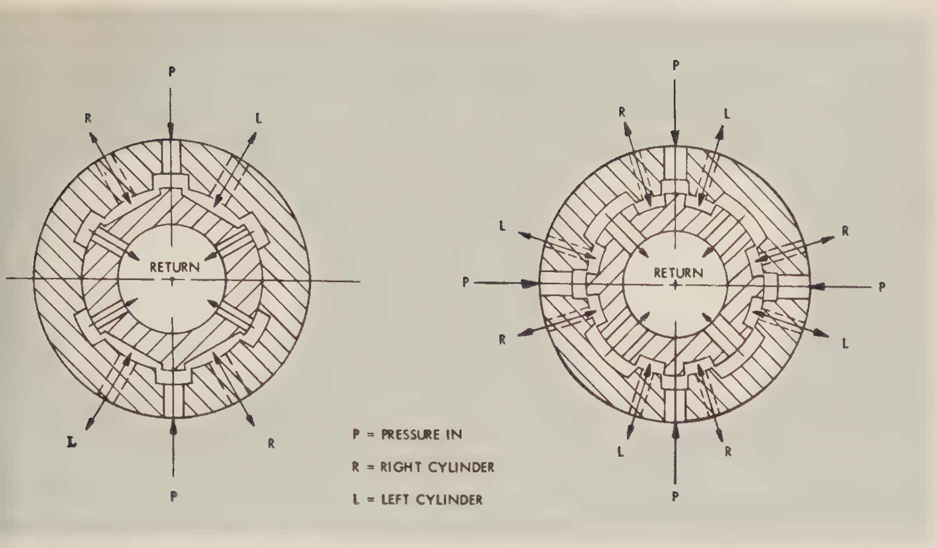


Fig. 6—In the original design of the valve spool (left), binding occurred between the spool and the valve body because of pressures caused by the oil on the projected area of the valve. This binding was eliminated by changing the design (right) to include another set of valving lands at 90° to the original set. The new design reduced the projected area of the valve under pressure to a minimum by reducing the width of the valve slots. These changes reduced the separating forces and dispersed them more evenly around the spool, thereby minimizing the deflection to a point where it caused no trouble.

obtained best by rotating the valve spool within the valve body. It was known that movement of the valve by axial movement of the worm was limited by the worm lead. The addition of levers or cams to increase the rate of movement would only increase the number of points for lash and deflection. This would result in loss of most of the multiplication during the first increments of movement, which were the most important.

To eliminate unnecessary friction and inertia it was decided that the hydraulic valve should be the first item in line between the steering wheel and the steering gear. Also, all possible points of friction should be on the output side of the gear to prevent such factors as thrust bearing preloads and seal drag from hampering free movement of the valve spool. The valve assembly would have to be designed so that the valve spool would be a free-floating member that would not become sticky due to misalignment between the valve assembly and the valve assembly actuating means.

A positive medium would have to be used for returning the valve spool to a neutral position. Such a medium should provide a centering force to the spool proportional to the output from the gear.

New Gear Design Used Rotary Valve

After establishing the design criteria and objectives, developmental work began on a new, improved power steering gear. The first experimental design for a new gear was very similar to the 1958 production model, but it had one significant difference. The hydraulic valve in the old gear functioned by axial motion, while in the new gear it functioned by rotary motion (Fig. 4).

The hydraulic valve consisted of a valve body and a valve spool of conventional three way, open-center construction. The valve lands, however, ran parallel to the axis rather than around the diameter of the spool, as in most valves. This construction allowed the valve to be actuated by rotation of the spool within the valve body, rather than by axial movement of the worm, or through any cam-type device. This resulted in faster actuation of the valve than was possible in past designs.

Design Evaluation Led to Improved Gear

A thorough evaluation of the design—obtained from the installation standpoint, through meetings with manufacturing, tooling, and processing personnel, and from experiences with engineering samples—brought out the following problems in the first design:

- The steering gear was too long, from the centerline of the pitman shaft sector gear to the upper end of the valve assembly, to fit into the limited space available in some of the 1959 cars
- The threaded adjustment of the torsion bar would not remain locked, due to reversing loads imposed by the torsion bar, allowing the valve to get out of balance
- The valve spool and valve body bound up under high pressures. The hydraulic forces between the valve body and valve spool caused these pieces to become egg shaped, thereby causing the parts to pinch on a plane 90° from the valve lands
- The valve spool could be actuated by side loads imposed by the upper steering shaft against the stub steering shaft, causing the stub steering shaft to cock in the short adjuster bearing. This resulted in movement between the valve spool and the valve body, causing poor recovery, and, in some extreme cases, self-steering was caused by a build-up in hydraulic pressure due to displacement of the spool radially within the valve body
- The construction of the steering gear housing with a bolted-on valve housing would present manufacturing problems in trying to hold close concentricities between the cylinder bore and the valve bore. A single piece housing would be easier to manufacture
- The rack-piston and ball nut assembly could be manufactured at less cost and with higher quality if the two parts were redesigned to be one piece
- The valve body could be machined more easily if the solid end were eliminated so that there would be a through hole.

As a result of a study of these problems, the rotary valve steering gear was redesigned.

Initial Design Problems Solved by New Gear

In the redesigned gear (Fig. 5), the length of the gear from the centerline of the pitman shaft sector gear to the upper end of the valve assembly was reduced by changing the location of the piston ring seal in the cylinder bore from the upper end of the housing to the lower end. The rack-piston and ball nut were combined into one piece, as were the steering gear housing and valve housing. The valve body was redesigned to provide a through hole by adding a torsion bar cap pinned to the valve body to prevent relative rotation of the two parts.

The threaded adjustment of the torsion bar to the stub steering shaft was replaced by dowel pins. These pins are drilled and pressed into place when the valve assembly is hydraulically balanced during the manufacturing operation. This, then, becomes a precision part which cannot become unbalanced due to tampering, and must be serviced only as an assembly.

Binding of the valve spool within the valve body was eliminated by the addition of another set of valving lands at 90° to the original set, and by reducing the projected area of the valve under pressure to a bare minimum through reducing the width of the valve slots. These changes reduced the separating forces, and dispersed them more evenly around the spool, thereby minimizing the deflection to a point where it caused no trouble (Fig. 6).

The actuation of the valve spool by side loads on the stub steering shaft was eliminated by the addition of a second needle bearing located at the lower end of the stub shaft and running against the torsion bar.

Since the only means of providing road feel is through the deflection of the torsion bar, it was necessary that the torsion bar be calibrated with respect to the

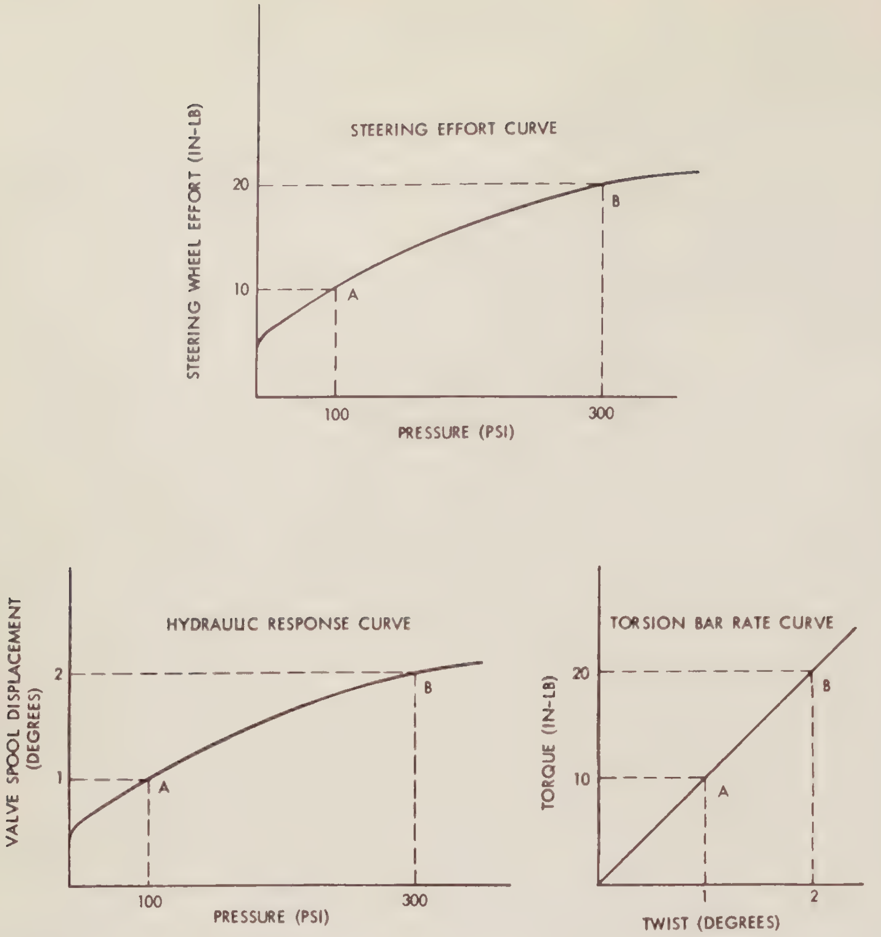


Fig. 7—Using the basic dimensions of a complete steering system and an assumed desirable steering effort pattern for the car, the relationship between steering wheel effort and hydraulic pressure can be plotted. Secondly, for any specific design of valve, the hydraulic response (valve spool angular displacement versus hydraulic pressure) can be determined experimentally. From these data it is a simple matter to determine the torsion bar rate. By varying the details of the valve porting to account for such factors as the manufacturing tolerances involved, system back pressure, and returnability, a very satisfactory compromise can be designed, as shown in the accompanying curves. It can be seen that in this example an effort of 10 in.-lb is desired to obtain a steering pressure of 100 psi, and an effort of 20 in.-lb is desired to obtain 300 psi. The plot of pressure versus valve spool displacement shows that an angular displacement of 1° is required to build 100 psi, and a displacement of 2° is required to build 300 psi. Plotting the effort for points *A* and *B* from the hydraulic response curve, the torsion bar rate curve is obtained. In this case the effort is 10 in.-lb per degree.

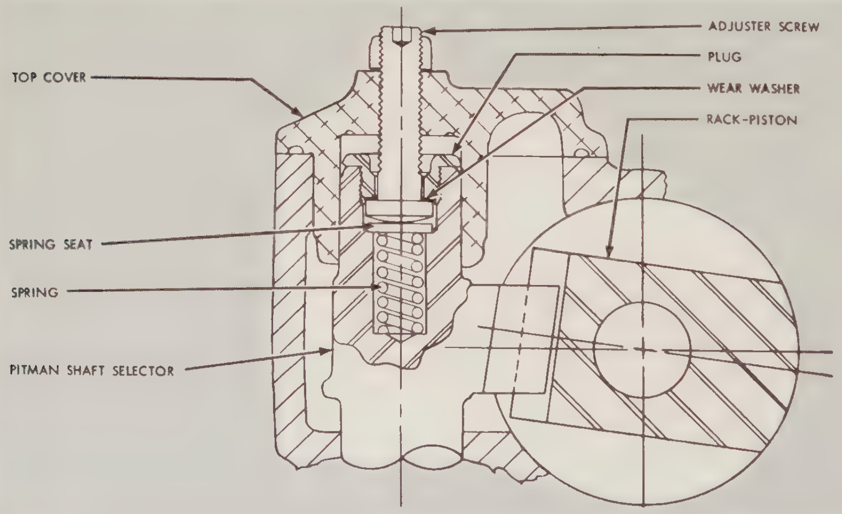


Fig. 8—Loss of the gear mesh preload between the rack teeth and the pitman shaft sector, when the steering gear is in the straight ahead position, is prevented in the final design of the gear by a wear washer located between the pitman shaft adjuster screw head and the threaded plug. The steering gear sector and rack teeth are preloaded by screwing the adjuster screw in (down) until all the lash is eliminated between the pitman shaft sector teeth and the rack teeth. As the teeth wear along their contact line, the pitman shaft sector is allowed to drop down, due to the wear washer wearing thinner, thereby preventing lash at the gears. The wear washer is caused to wear by a preload spring creating a constant force against it, plus a variable force against the washer due to hydraulic pressure against the end of the pitman shaft sector when pressure is built up on the lower end of the cylinder.

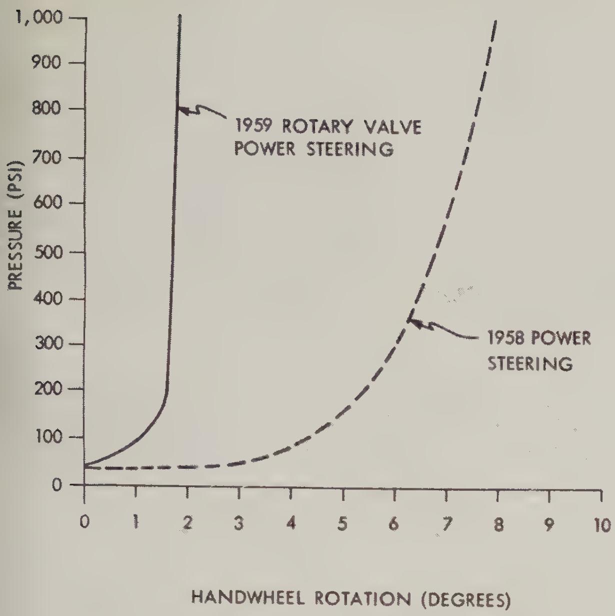


Fig. 9—A comparison of steering gear sensitivity between the 1959 rotary valve power steering gear and the 1956-58 in-line power steering gear shows the higher sensitivity of the new gear.

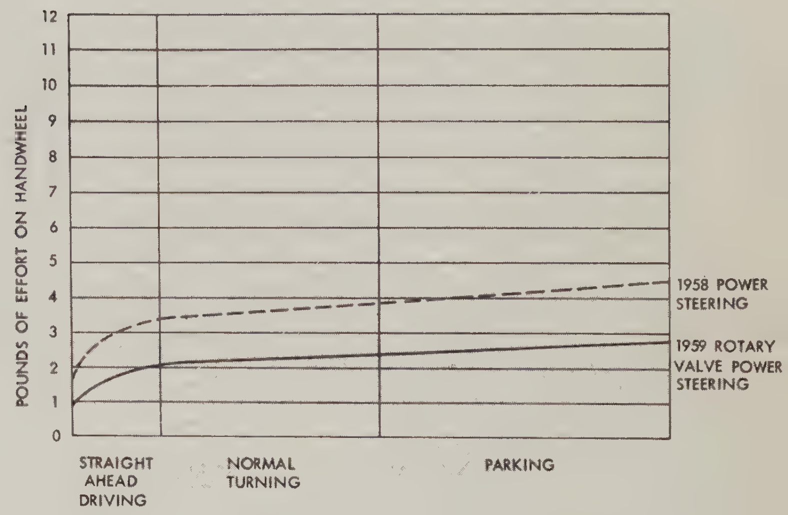


Fig. 10—A comparison of handwheel effort (force required to turn the steering wheel) between the 1959 rotary valve and the 1956-58 in-line power steering systems shows the lesser effort required for steering with the new gear.

valve assembly. The size of the torsion bar was determined finally by road tests to find the correct amount of steering effort to give a satisfactory amount of road feel. The initial design of the valve and torsion bar, however, was accomplished by use of non-empirical calculations (Fig. 7).

Loss of the gear mesh preload between the rack teeth and the pitman shaft sector with the steering gear in the straight ahead position was prevented by means of a wear washer located between the pitman shaft adjuster screw head and the threaded plug (Fig. 8).

In meeting the design objectives to reduce size, weight, number of parts, and number of external seals, the final design is 0.83 in. shorter at the upper end, weighs one lb less, has 17 fewer parts, and nine fewer seals than the preceding production power steering gear design. The new gear provides hydraulic valve response in less than one degree of handwheel movement (Fig. 9) with a down-the-road effort of slightly less than one lb on the rim of the handwheel. It has a maximum parking effort of three lb, while retaining a desirable amount of road feel (Fig. 10).

Summary

As a further improvement over an already satisfactory power steering gear design, Saginaw Steering Gear Division engineers developed a new gear incorporating a rotary hydraulic valve.

The improved design began with a listing of basic design criteria by engineers. The results of a comparison of these criteria with established design objectives directed research to the principle of the rotary valve. Moving into research and development, the engineers constructed an experimental gear incorporating their innovations. A thorough evaluation of the experimental gear revealed certain production, tooling, and operational problems, and enabled the engineers to design a second, more refined, experimental gear. The second model met the initial design objectives and criteria, and operational and production requirements, and was accepted for production and installation on 1959 model passenger cars.

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The Application of Mathematics to a Basic Study of Automobile Control and Stability Problems

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Computers aid in analyzing lateral motions induced by steering wheel displacements

Deviation of an automobile from a straight-ahead course is called lateral response, which can take the form of three lateral motions: yaw, roll, or sideslip. A study of dynamic lateral response of an automobile to predict its reaction to steering wheel displacements has always been difficult, due to lengthy and involved mathematical computations required in vehicular analysis work. The advent of analog and digital computers, however, has served to lessen the complexity of such a dynamic study. Recently, the GM Research Laboratories undertook a basic study of automobile control and stability problems. Three simultaneous, linear differential equations were developed which described the three lateral motions of an automobile. Included in the three equations were 20 variables each of which had a particular effect on control and stability. Once the equations had been verified, computers were then used to analyze the control and stability performance of a car as it would be affected by each of the variables. The results of this program, which represents but a first step in an overall systems analysis of a general automobile steering study, have provided a basic understanding of the effects of various parameters on the dynamic lateral response of an automobile.

STABILITY and control of an automobile, sometimes called the handling problem, deals with providing the proper steering behavior to an automobile. This, in turn, means: (a) providing the automobile with directional sense so that it will run straight of its own accord, and (b) providing sufficient steering control so that the automobile can be steered easily along a selected path. In its simplest sense, the study of automobile stability and control is a study of lateral motions induced in a car by steering inputs from the driver.

The entire system of automobile steering response consists of a driver, a steering gear, and an automobile (Fig. 1). The driver, acting on stimuli sensed either from within himself or from external sources, supplies information input to set the system in operation. This input may be the desire to go straight, to pass another car, or to turn a corner. In response to the information input, the driver makes a decision and applies torque to the steering wheel, turning it to a given position. This action, working through the steering gear, turns the front wheels of the car to some angle, which begins to change the path of the car down the road. The change in path by the automobile is called *lateral response.*

Although the driver steers the automobile by a combination of steering torques and steering displacements, it is possible to study separately the responses to these two kinds of steering inputs. The stability and control characteristics associated with a fixed steering wheel, or the response produced by a steering wheel displacement, are called *fixed control* characteristics. Conversely, the characteristics associated with a free steering wheel, or the response produced by a steering torque, are called *free control* characteristics. In the discussion which follows, the automobile component of the steering response system (Fig. 1) will be dealt with, and particularly its lateral fixed control response to front wheel steering inputs.

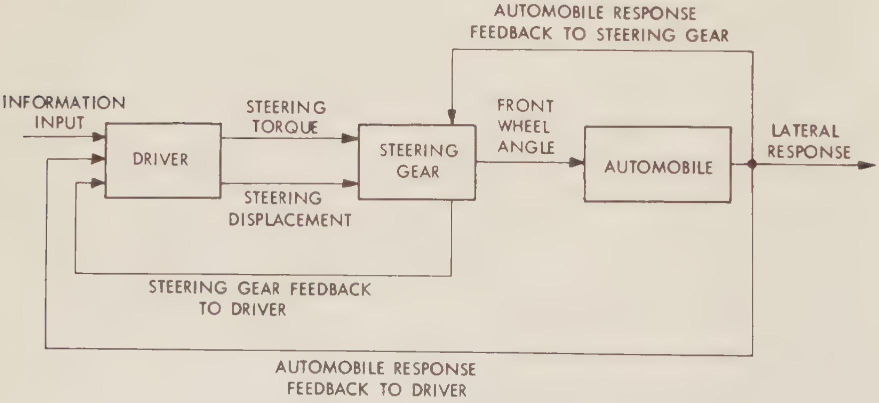

AUTOMOBILE RESPONSE FEEDBACK TO STEERING GEAR
INFORMATION INPUT
STEERING TORQUE
DRIVER
STEERING GEAR
FRONT WHEEL ANGLE
AUTOMOBILE
LATERAL RESPONSE
STEERING DISPLACEMENT
STEERING GEAR FEEDBACK TO DRIVER
AUTOMOBILE RESPONSE FEEDBACK TO DRIVER

Fig. 1—The automobile steering response system consists of three basic components—the driver, the steering gear, and the automobile. This block diagram shows the interrelation of the components. The driver steers the automobile by a combination of steering torques and steering displacements which cause a change in the path of the car. This change in path is called the *lateral response.* Besides the forward flow of effects from the driver to the lateral response, there are several feedback loops. For example, the lateral response is fed back to the steering gear as a torque and to the driver in the form of visual inputs and lateral acceleration. There also is steering wheel torque feedback from the steering gear to the driver.

Equations Developed to Describe Vehicle Motion

The automobile motions dealing with the study of lateral fixed control response are yawing, rolling, and sideslipping (Fig. 2). Yawing is the angular velocity about the vertical reference axis of the car. Rolling is the angular velocity about the fore and aft horizontal axis of the car. Sideslipping pertains to the side velocity and is defined by the sideslip angle (the angle whose tangent is sideslip velocity divided by forward velocity).

The first attempt by the GM Research Laboratories to describe the lateral motions of a car was made in 1953 and was based on the application of differential equations[1]. Later in the same year, the aid of the Cornell Aeronautical Laboratories was enlisted to study stability

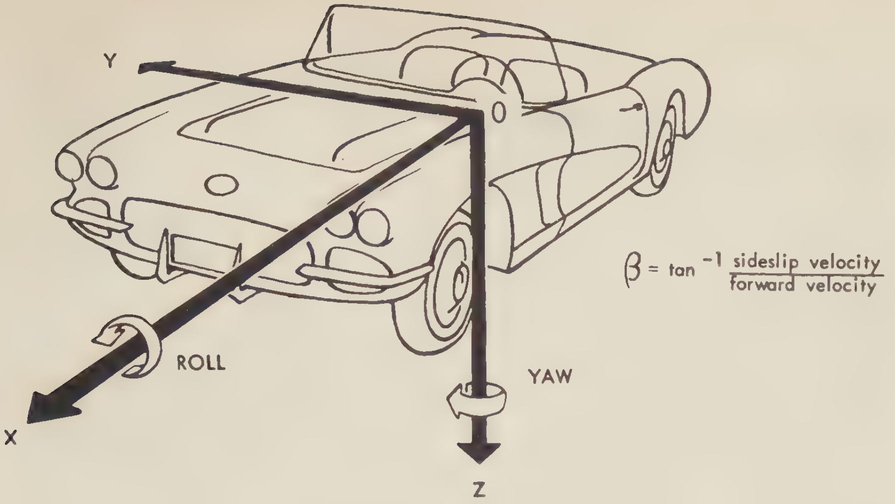

Y
0
ROLL
X
YAW
Z
$\beta = \tan^{-1} \frac{\text{sideslip velocity}}{\text{forward velocity}}$

Fig. 2—The axis system of a simplified automobile is fixed effectively in the unsprung mass (wheels and tires) so that the Y and X axes do not roll with the sprung mass (body, frame, and engine), but remain parallel and perpendicular to the road surface, respectively. The car is considered to have a constant forward velocity along the X axis (roll axis). For the small angles of sideslip usually encountered, the sideslip angle β is defined as the side velocity along the Y axis divided by the forward velocity along the X axis. Yawing is the angular velocity about the vertical Z axis.

and control. The extensive experience of Cornell with stability and control problems in the aircraft field, and especially their advanced instrumentation techniques, were brought to bear upon the problem[2]. The result of this joint effort was a verified set of three equations which described the lateral response of a car to steering inputs. These three simultaneous linear differential equations described side force, yawing moment, and rolling moment (Table I).

Vehicle Parameters Measured

The initial step in the experimental program was to determine the actual values of the mass, chassis, and tire characteristics of a test car. The yawing moment of inertia I_Z was measured by hanging the car on four cables and swinging it as a multifilar pendulum. By measuring the frequency of the yaw oscillation, it was possible to compute the yawing moment of inertia.

The rolling moment of inertia I_X and the product of inertia linking the yawing and rolling motions I_{XZ} were determined by oscillating the car on knife edges about a horizontal axis. The rolling moment of inertia was found from the rolling oscillation frequency, and the product of inertia I_{XZ} was found from the yawing moment produced by the rolling oscillation. The total weight and the longitudinal center of gravity were obtained by a simple weighing process.

Chassis characteristics, such as roll spring rates, rear axle roll steer, and front wheel camber due to body roll, were determined by standard General Motors Proving Ground tests. The damping characteristics of the shock absorbers were determined by use of a stroking machine. The damping produced by the shock absorbers in the suspension system was determined by a simple geometrical calculation.

Tire side force and moment characteristics were supplied by a tire manufacturer who obtained the data by running the tire on a moving drum. These tire characteristics were determined for wide variations in tire pressure and in the load

LATERAL RESPONSE EQUATIONS

SIDE FORCE EQUATION:

$$(M)\,(V)\,(\dot{\beta} + r) + (M_S)\,(h)\,(\dot{p}) = (Y_\beta)\,(\beta) + (Y_r)\,(r) + (Y_\delta)\,(\delta) + (Y_\phi)\,(\phi)$$

YAWING MOMENT EQUATION:

$$(I_Z)\,(\dot{r}) - (I_{XZ})\,(\dot{p}) = (N_\beta)\,(\beta) + (N_r)\,(r) + (N_\delta)\,(\delta) + (N_\phi)\,(\phi)$$

ROLLING MOMENT EQUATION:

$$(I_X)\,(\dot{p}) + (M_S)\,(h)\,(V)\,(\dot{\beta} + r) - (I_{XZ})\,(\dot{r}) = (L_p)\,(p) + (L_\phi)\,(\phi)$$

M = mass of automobile
V = forward velocity
β = sideslip angle
r = yaw velocity
M_S = sprung mass of automobile
h = height of sprung mass center of gravity above roll axis
p = roll velocity
Y_β = side force per unit of sideslip angle
Y_r = side force per unit of yaw velocity
δ = front wheel steer angle
Y_δ = side force per unit of front wheel steer angle

ϕ = roll angle
Y_ϕ = side force per unit of roll angle
I_Z = yawing moment of inertia
I_X = rolling moment of inertia
I_{XZ} = product of inertia
N_β = yaw moment per unit of sideslip angle
N_r = yaw moment per unit of yaw velocity
N_δ = yaw moment per unit of front wheel steer angle
N_ϕ = yaw moment per unit of roll angle
L_p = roll moment per unit of roll velocity
L_ϕ = roll moment per unit of roll angle

Table I—The equations tabulated at the right describe the three lateral motions of an automobile. In each equation, the mass, inertia, and acceleration terms are given on the left, while the forces and moments that cause the accelerations are given on the right. Each of the force terms on the right consist of the product of some motion variable and a stability derivative. For example, in the side force equation, δ is the front wheel steer angle put in by the driver, and Y_δ is the stability derivative with the dimensions of force per unit of front wheel steer angle. The stability derivatives appear in each equation and are composed of various car parameters, such as tire lateral stiffness, weight distribution, and suspension characteristics. In all, there are 20 car parameters included in the three equations of motion. In deriving these equations, it was assumed that the tires, springs, and shock absorbers all behaved linearly, and that the car operated on a flat road with no wind blowing so that the only force input to the system was caused by the driver turning the front wheels of the car.

carried by the tire.

In addition to providing numerical data to insert in the three equations of lateral motion, the experimental tests demonstrated that the assumption of linearity for the various car parameters was valid for lateral motions of a reasonable magnitude.

Equations Verified by Response Tests

The three equations of lateral motion were verified by response tests made with a test car containing instrumentation necessary to measure lateral response (Table II). Both left and right front wheel positions were measured and then averaged to yield the effective front wheel angle. Since it was not convenient to measure the sideslip angle, the total lateral acceleration along the Y axis was measured with a lateral accelerometer. The pitch attitude, while not a lateral degree of freedom, was measured to determine if any coupling occurred between the vertical and lateral motions. The outputs of the various motion sensing instruments were recorded on an oscillograph.

MEASURED VARIABLES AND ASSOCIATED TRANSDUCERS

VARIABLE OF MOTION	SENSING INSTRUMENT
Left Front Wheel Position (δ_L)	Angular Potentiometer
Right Front Wheel Position (δ_R)	Angular Potentiometer
Steering Wheel Position (δ_{SW})	Angular Potentiometer
Lateral Acceleration (η_Y)	Lateral Accelerometer
Roll Attitude (ϕ)	Attitude Gyro
Pitch Attitude (θ)	Attitude Gyro
Angular Yaw Velocity (r)	Rate Gyro
Angular Roll Velocity (p)	Rate Gyro
Forward Velocity (V)	Fifth Wheel Generator Set

Table II—Tabulated here are the various sensing instruments used to measure the motion variables affecting lateral response.

In the early stages of the experimental work, it was assumed that information would be recorded in the frequency range of 0 to 10 cycles per second. After the first shakedown runs, however, it was discovered that both engine vibrations and wheel vibrations at the natural frequency of the wheel on the tire were being picked up by the sensing instrumentation. These unwanted vibrations were removed with low pass filters utilizing a tuned galvanometer so that only frequencies from zero to three cycles were recorded.

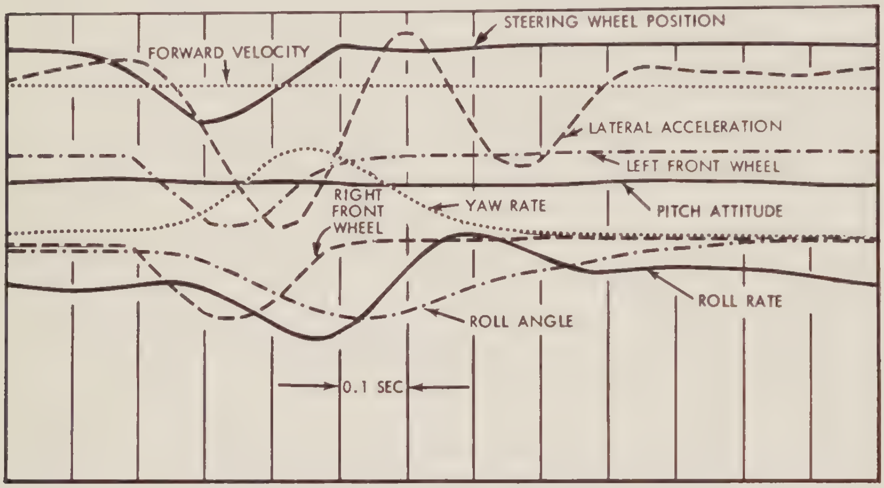


Fig. 3—This record shows the transient response of a test car to a pulse input of front wheel angle (pulse steering input). All the motion variables are shown here. It is of interest to note that no appreciable change in the pitch attitude of the car occurred during the test.

Transient response tests were conducted by first stabilizing the forward speed of the test car and then performing a steering maneuver and recording the resulting car responses (Fig. 3). Numerous tests were made using both step and pulse steering inputs. The step and pulse steering inputs used in the test work were only approximations to the mathematically pure step and pulse inputs used by servo engineers. The use of the step and pulse inputs with different harmonic content made certain that all frequencies of interest were introduced as inputs at some time during the experimental program. In addition to varying the inputs, response data were obtained in which vehicle parameters, like tire character-

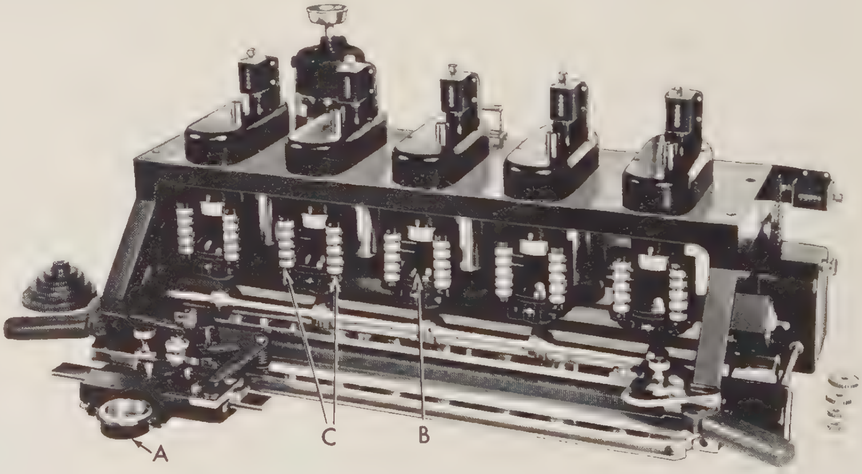
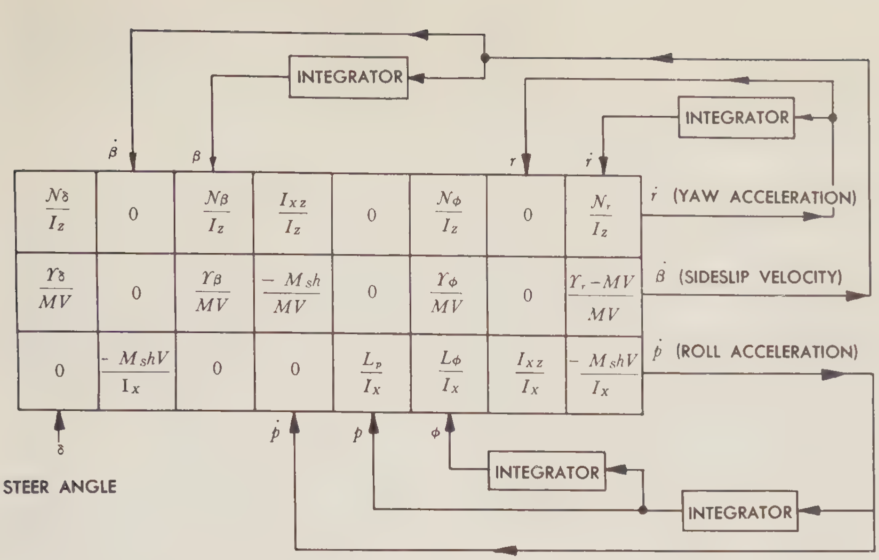


Fig. 4—The rolling sphere harmonic analyzer shown here was utilized by the GM Research Laboratories to evaluate frequency response integrals. In operation, the transient curve to be analyzed is followed with a cross-hair eyepiece *A* attached to the analyzer. As the eyepiece is moved along the curve from the starting point (initial conditions zero) to the point where steady state is reached, it actuates a number of rolling ball integrators *B*. Each integrator is equipped with a recording dial *C*. After the eyepiece has completed the transverse of the curve, the individual dials produce readings which are proportional to the real and imaginary components of the Fourier integral. The analyzer produces five harmonics for one traverse of the transient curve.



YAW ACCELERATION EQUATION:

$$\dot{r} = \left(\frac{N_\delta}{I_z}\right)\delta + (0)\,\dot{\beta} + \left(\frac{N_\beta}{I_z}\right)\beta + \left(\frac{I_{xz}}{I_z}\right)\dot{p} + (0)\,p + \left(\frac{N_\phi}{I_z}\right)\phi + (0)\,\dot{r} + \left(\frac{N_r}{I_z}\right)r$$

Fig. 5—An analog computer was used to determine transient response. Shown here is a block diagram illustrating the general procedure used. (See Table I for a definition of symbols shown in the block diagram.) Any motion variable, for example the yaw acceleration $\dot{r}$, was found by summing horizontally the products of the term in each box and the corresponding vertical input, as indicated by the equation for yaw acceleration. This equation is the same as the yawing moment equation shown in Table I. The rate of change of sideslip and the rolling acceleration were found in a similar manner. Each row represented a summation with the quantity in each block being the gain factor applied to the various motion variables. The complete simulation of the three lateral response equations (Table I) on the analog computer required only 14 amplifiers. At the present time, no non-linear equipment is used. Future work, however, will require the addition of some function generators and multipliers.

istics and weight distribution, were varied from normal. With these response data in hand, a comparison was made between the actual measured responses and the responses predicted by the differential equations.

Theory Compared With Experiment

A comparison between theory and experiment was made on the basis of frequency response. That is, the steady state sinusoidal response of the test car induced by a sinusoidal input of front wheel steer angle was determined both theoretically and experimentally. The theoretical frequency response was obtained by first applying the Laplace transformation to the system of equations and then replacing the Laplace operators by $j\omega$, where ω equaled the frequency of front wheel oscillation and j equaled $\sqrt{-1}$. The determination of the yawing, rolling, and sideslipping frequency responses was then a matter of algebraic computation, which was quickly accomplished by a digital computer. The experimental frequency responses were determined from transient responses similar to those shown in Fig. 3. This procedure was based on the use of the Fourier integral.

Under certain circumstances, the Fourier integral enables a time function of a system $f(t)$ to be transformed into a complex frequency function $F(j\omega)$. The Fourier integral may be expressed as:

$$F(j\omega) = \int_0^\infty f(t)e^{-j\omega t}\,dt.$$

Since this integral must be evaluated along the interval from zero to infinity, it is necessary to know the behavior of $f(t)$ for an infinite time. This is arranged most easily by applying a disturbance to the system such that $f(t)$ reaches a steady value in some finite time T. Under these conditions, the frequency function $F(j\omega)$ may be broken into its real and imaginary parts as follows:

$$F(j\omega) = R + jI$$

where

$$R = \int_0^T f(t)\cos\omega t\,dt - \frac{f_T}{\omega}\sin\omega T$$

$$I = -\int_0^T f(t)\sin\omega t\,dt - \frac{f_T}{\omega}\cos\omega T$$

These integrals may be evaluated in a number of ways[3]. The GM Research Laboratories utilized a rolling sphere

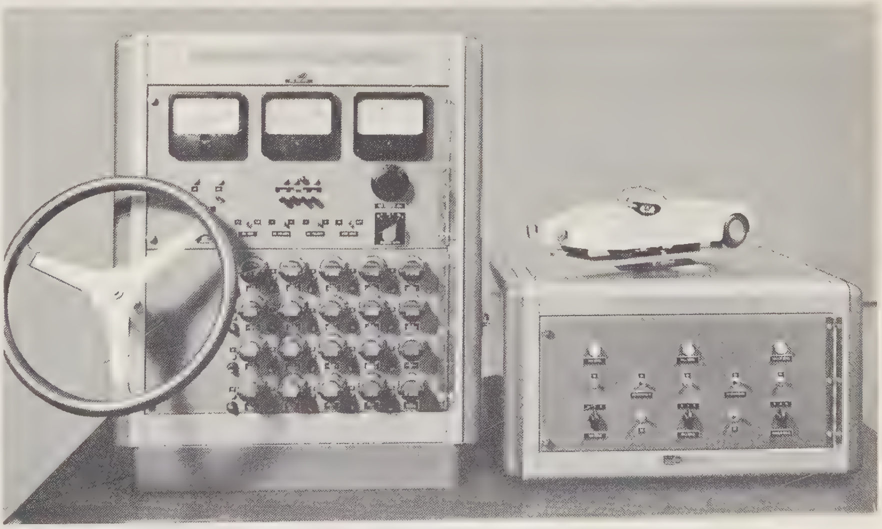


Fig. 6—The real-time automobile handling simulator (right) consists of a small, special purpose, analog computer which can be "steered" by turning a steering wheel attached to the computer. Movement of the steering wheel causes "steering angle" voltages to be introduced into the analog computer circuit. The computer then solves the lateral equations of motion of the automobile. The voltages proportional to yaw, roll, and sideslip are applied to a small servo-driven car. This model car can yaw and roll, and also demonstrate sideslip by means of a pointer mounted on the hood of the car which indicates the direction in which the car is actually going. The analog computer also includes a meter which indicates applied steer angle. By use of a ganged potentiometer, which has an element in the input, or feedback, of certain of the amplifiers, it is possible to set the forward speed of the car at any point between 30 mph and 100 mph. Steering gear ratios can be altered by means of a selector switch. By inserting the proper car parameters on the potentiometers, a wide variety of automobiles can be "driven" on this computer.

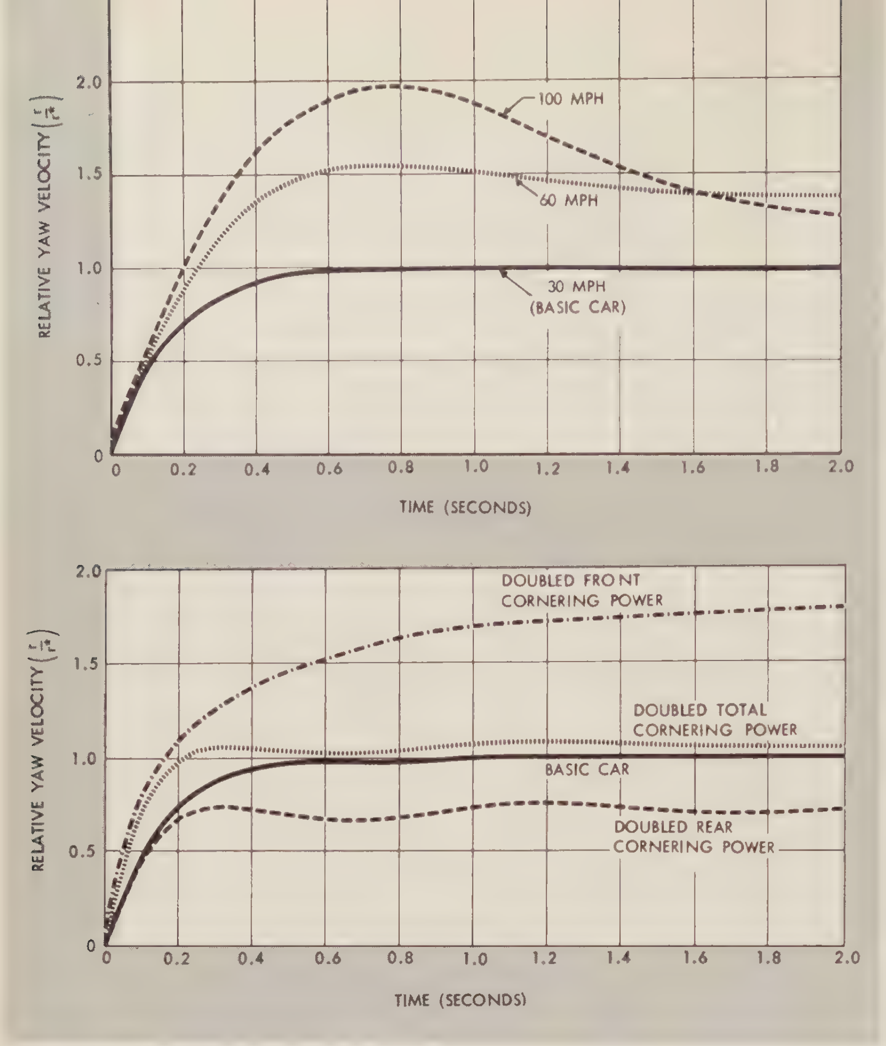


Fig. 7—Various tests were conducted to study the effect of car speed on yaw. An increase in car speed caused an overshoot to develop in the yaw response (top). This was due to a decrease in the yaw damping characteristics of the tires as the speed increased. The curves shown at the top were normalized with respect to the steady state yaw response of the car traveling at 30 mph (r^*). The lateral stiffness, or cornering power of tires, also had an effect on yaw response. When the cornering power of the front tires was doubled (bottom), the car was placed in an oversteer condition, characterized by a large steady state response which was reached quite slowly. Doubling the cornering power of the rear tires reduced the steady state response of the system. Doubling the cornering power of both the front and rear tires produced a quicker response with little change in the steady state value.

harmonic analyzer (Fig. 4).

To obtain experimental response data for comparison, it was necessary to analyze the input to the system (steering angle) and the various system responses. When this was done, a comparison was then made between theoretical and experimental responses. Excellent agreement was obtained between the predicted yawing velocity response and that actually obtained on the road. Good agreement also was obtained for the rolling and sideslipping motions.

The use of the frequency response technique had two important advantages: (a) it provided for easy removal of dynamic effects produced by the filters in the recording channels, and (b) it provided a more general solution than would a transient response. The first experimental frequency responses obtained did not match the equations exceptionally well. Through the use of the frequency response plot, however, it was possible to determine some additional terms which were added to the equations of motion.

Computers Simulate Vehicle Lateral Response

After the equations of motion had been verified, they were then used to study the effects of the various car parameters on its lateral response. Both digital and analog computers were used in this study. The analog computer was used to determine only the transient response. The digital computer was used to check the transient response obtained by the analog computer and also to determine the frequency response and the roots of the characteristic equation of the automobile steering response system.

Analog Computer Studies

The mechanization of the differential equations on the analog computer followed the standard procedure of summing the various quantities which determine the various accelerations in the system, and then integrating acceleration to velocity and velocity to displacement (Fig. 5).

Analog computer studies are normally run in *slow time*. That is, the computer is slowed down relative to clock time, or real time, and the results recorded on an oscillograph. To demonstrate the lateral motions of an automobile caused by steering inputs, a real-time simulator has been constructed by the GM Research Laboratories for such studies (Fig. 6). With this simulator the computed car responses occur at exactly the same rate as do the responses of a real car.

Digital Computer Studies

The transient response was determined on the digital computer by a Runge-Kutta method[4]. Values of the motion variables were determined at each 1/40-second of problem time. Determining the frequency response required the solution of three simultaneous complex equations which resulted when the complex operator $j\omega$ was inserted in the equations. This solution utilized a matrix subroutine which converted a 3 × 3 complex matrix into a 6 × 6 real matrix. The roots of the characteristic equation were determined

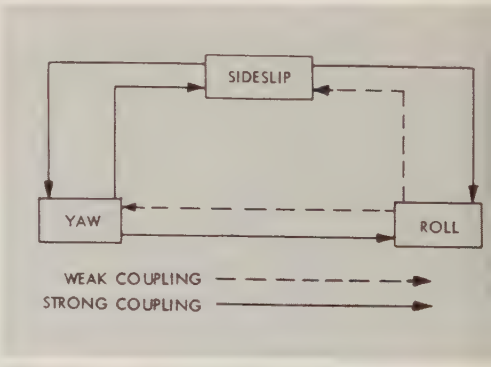


Fig. 8—A study of the relative strength of coupling between the three kinds of vehicle motion showed that a weak coupling existed between roll and the other two motions. Although this coupling is weak, it is often the reason that a particular car is either stable or unstable, particularly with regard to yaw.

by first finding the characteristic equation by direct expansion, and then solving the equation by a Newton-Raphson method[5].

Parameter Effects On Vehicle Evaluated

The computer studies indicated that several parameters affect the lateral response of an automobile, but two—speed and cornering power—have a particularly important effect on yaw.

The studies showed that as the speed of a car was increased, the yaw response developed an overshoot (Fig. 7—top), caused by a decrease in the yaw damping of the tires. When the cornering power, or lateral stiffness, of the front tires was doubled the car was placed in an oversteer condition (Fig. 7—bottom). This condition was characterized by a large steady state response, which was reached quite slowly. Doubling the rear cornering power reduced the steady state response of the system. Doubling both the front and rear tire cornering power produced a quicker response with little change in the steady state value. Other parameters in the automobile steering response system were explored and their effects on various lateral responses cataloged.

As a result of the extensive examination of the solutions of the three equations of motion, an understanding was obtained of the effects of the various car parameters on the lateral response of a car. In addition to this somewhat specialized information, a number of general observations were made regarding the lateral response.

The first effect observed pertained to the coupling of the lateral response motions (Fig. 8). Yaw and sideslip were strongly coupled, but there was only a weak coupling linking roll to yaw and sideslip. This weak coupling is often the reason that an automobile is either stable or unstable, particularly in yaw.

A second interesting aspect of the study pertained to the modes of motion of an automobile when in a state of free lateral oscillation. When there is no steering input the set of equations representing the lateral behavior of the car is mathematically equivalent to the equations representing two linked vibrating systems. If the linkage between the systems is weak the vibration, or mode of motion, of each system is largely independent of the other system. When this is the case, the systems can be easily studied separately. Consequently, determination of the modes of motion was made with the anticipation that there would be a well defined "directional" mode of motion consisting of yawing and sideslipping, and also a "rolling" mode of motion. The modes were found by calculating the roots of the characteristic equation of the system and then inserting these roots in the lateral motion equations. This study showed that there are, in general, no distinct modes of motion, but under certain conditions it is possible to find modes of motion which are primarily directional and rolling in nature.

A third interesting result of the study showed that the equations of motion predict lateral motion responses which are compatible with on-the-road observations of oversteer and understeer characteristics made by test engineers. Oversteer and understeer characteristics[6] of an automobile (Fig. 9) may be calculated from terms contained in the three equations of motion. The speed at which an oversteer car becomes unstable also may be computed.

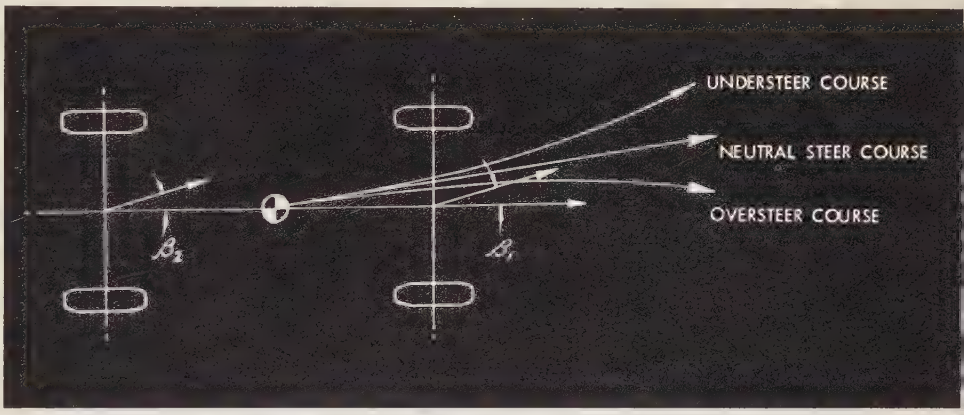


Fig. 9—Early studies of lateral response in vehicles often was concerned with oversteer and understeer characteristics. Because of the nature of pneumatic tires, they must run at slip angles β_1 and β_2 to produce side forces. If β_1 is greater than β_2, the path followed by the car curves away from the side force. This is called *understeer*. Conversely, if β_2 is greater than β_1, the path of the car curves toward the side force, which is called *oversteer*. The directional stability of an understeering car tends to increase with increasing speed, while the directional stability of an oversteering car tends to decrease.

Conclusions

To date, the result of the research program dealing with automobile control and stability problems consists of a verified linear model of the automobile. The work so far represents only the first step in an overall systems analysis of the general automobile steering problem. In addition to a study of the nonlinearities encountered when the amplitudes of the lateral motion are large, further work will be necessary with regard to the steering gear and the human operator. In the last analysis, the determination of desirable handling qualities from the point of view of the driver is the most important result that will come from this research effort.

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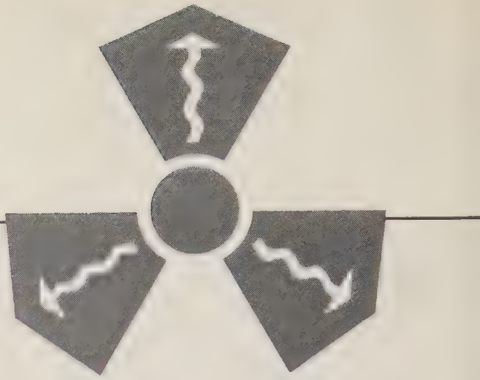
A Radioisotopic Study of Leveling in Bright Nickel Electroplating Baths



In pursuit of a program aimed at a better understanding of the mechanism by which organic addition agents influence the electrodeposition of nickel metal, it was considered feasible to utilize the technique of labeling the organic compounds with radioactive isotopes. Thus, a radioactive organic addition agent, sodium allyl sulfonate, containing the beta emitting S-35 atom, has been synthesized and used as a component in a bright nickel plating bath to produce leveling nickel deposits. A radiochemical technique has been developed to locate radioactivity in the deposited metal. Autoradiograms and counting data from the nickel foils which were produced show that the radioactive addition agent, or its reduction products, is preferentially adsorbed or co-deposited on the high points of an irregular surface. On the basis of this evidence, confirmation is obtained for a theory which accounts partially for leveling action in the type of bright and leveling nickel solutions considered in this study.

In the sequence of events which leads to the production of brilliant, chromium plated automobile parts, the chromium must be deposited on a bright and smooth nickel surface. Such a surface may be produced by buffing a matte or a semi-bright nickel deposit. As an alternative, it is possible to deposit directly, from baths containing organic addition agents, a nickel plate which is bright and which also tends to fill in the micro-irregularities of a surface to make it smooth. From the standpoint of economics, it is readily apparent that any process which eliminates buffing operations is desirable.

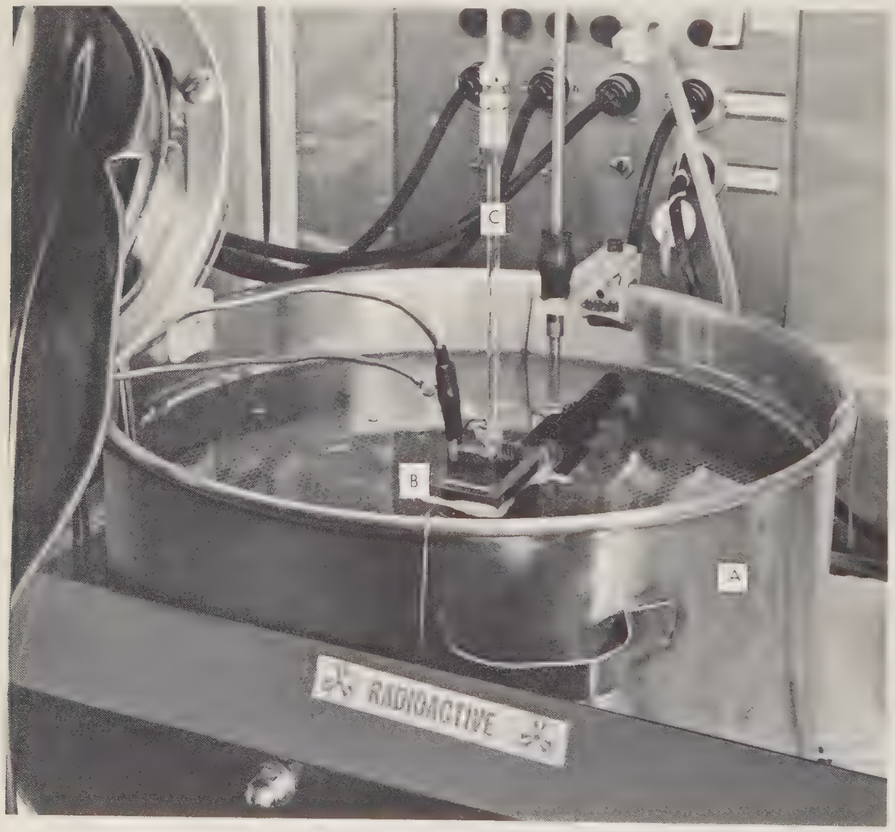


Fig. 1—The plating apparatus used in the study of leveling effects was contained in a glove box to prevent the spread of radioactivity. A constant temperature water bath *A* was used to maintain a temperature of 56° to 58° C. The plastic cell *B* contained the plating solution, nickel anode, and serrated brass cathode. An agitator rod *C* was connected to an oscillating stirrer outside the glove box.

Leveling Helps Compensate for Surface Irregularities

The recognition that certain plating solutions can deposit more than the expected amount of metal in the small recesses of scratches in the basis metal to produce a smoother surface was reported by 1940 and also recognized in the patent literature, prior to the noteworthy contribution of Gardam[1] in 1947. Although this phenomenon subsequently has been known by a variety of terms, such as *smoothing action* and *hiding power*, it is, in this paper, called *leveling*.

Leveling has been defined by Thomas[2] as the ability of an electroplating solution to produce deposits relatively thicker in small recesses and relatively thinner on small protrusions with an ultimate decrease in the depth or height of the small surface irregularities. If an irregular surface is considered to be a series of peaks and recesses, then any action which deposits more metal in a recess than on a peak contradicts normal plating expectancy. In normal plating, more metal would be deposited on the high current density areas which are the high points, or peaks, of an irregular surface. In addition to its practical significance, therefore, the phenomenon of leveling poses a problem which has interested many investigators, and which has led directly to the study reported here. For a comprehensive review of the whole problem of leveling, the report of Leffler and Leidheiser[3] is most informative.

There has been much speculation concerning the mechanism by which the phenomenon of leveling may occur in

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Radiotracer checks effect of organic additive on selective deposition of metal

the electrodeposition of bright nickel. The situation is complicated by lack of agreement among investigators as to the effect on leveling of various plating conditions, including current density, temperature, agitation, and addition agent concentration[2,4-7]. There is, however, general agreement that an increase in polarization accompanies leveling action[4,6-12].

Some theories of the phenomenon assume that an organic addition agent which promotes leveling is adsorbed or co-deposited onto the high points, or peaks, of an irregular surface[2,4,7-15]. This adsorbed material presumably leads to localized polarization which partially inhibits the deposition of metal at the peaks and diverts current flow to recessed areas. Recent work of Watson and Edwards[7] supports this view. They show conclusively that there is increased polarization in solutions possessing leveling ability. Further, they apparently have identified the presence of addition agents in nickel deposits by a staining technique which, for example, caused a darkening on the peak areas of a deposit obtained from a bath containing thiourea. In his study of laminations, Vanderkooi[15] considers that the dark bands present in deposits contain either included addition agents or their reduction products. These observations point up the need for a technique which will show unambiguously the location of addition agents in leveling nickel deposits.

With the particular solutions used in this study, the deposits formed are laminated in structure. Metallographic examination of such deposits shows alternate light and dark bands which apparently have been produced by some type of rhythmic process. The mechanism by which these laminations are produced is not clearly understood. While it is known that leveling can be achieved in unlaminated deposits, a theory which can account at least in part for leveling must be compatible with lamination formation.

Study Planned to Investigate Leveling

The purpose of this study was twofold: first, to determine if an organic agent known to promote leveling was preferentially adsorbed or co-deposited on the high points of an irregular surface and, second, to develop radiotracer techniques suitable for determining the location, within electrodeposits, of a radioactive organic addition agent.

The work of Vanderkooi[15] has shown that the brightener system of sodium allyl sulfonate[16] and N-allyl quinaldinium bromide[17] produces bright, leveling, and laminated nickel deposits. These organic addition agents were used in a Watts-type nickel bath to produce the electrodeposits examined in this study. The sodium allyl sulfonate was radioactive due to the use of the beta emitting S-35 atom in its synthesis. To examine the deposits for the presence of radioactivity it was necessary to develop counting and autoradiographic techniques.

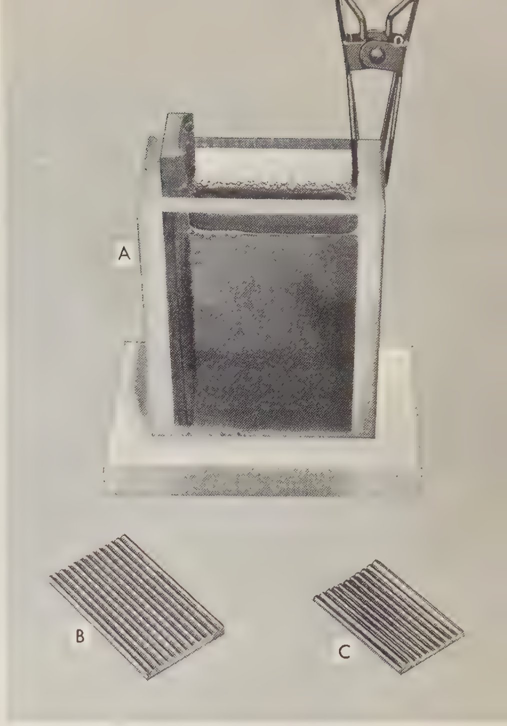

Fig. 2—The plastic cell *A* measured 2 in. long by 1 in. wide by 3 in. deep. The nickel anode is shown in place. The grooved brass cathode *B* measured 1.75 in. by 1.0 in. by 0.125 in. The grooves were 0.030 in. deep with an included angle of 90°. They were cut into one face of the cathode parallel to the long edge. There were 13 peaks and 12 recesses. Nickel foils *C* were deposited on the cathode and then removed for examination.

Radioactive Sodium Allyl Sulfonate Synthesized

The micro-synthesis of sodium allyl sulfonate containing the radioactive iso-

PLATING CONDITIONS AND RESULTS

FOIL NUMBER	PLATING TIME (MINUTES)	AMPERES	CURRENT DENSITY (ASF.)	BRIGHTENER CONCENTRATION (Mg. PER Ml.)			RESULT
				NO. 1 ACTIVE	NO. 1 INACTIVE	NO. 2 INACTIVE	
21	100	0.3	27.3	3	0	0.6	Foil intact, dull
25	100	0.3	27.3	6	0	0.6	Foil intact, dull
26	100	0.2	18.2	6	0	0.6	Foil intact, dull
31	100	0.2	18.2	3	198	0	Foil intact, bright, brittle
34	100	0.2	18.2	3	302	0	Foil intact, dull, brittle
36	100	0.2	18.2	3	198	0.4	Foil intact, dull, very brittle
38	100	0.2	18.2	3	198	0.5	Foil intact, bright, brittle
41	100	0.2	18.2	3	198	0.3	Foil intact, dull, brittle
51	40	0.45	41	3	150	0.2	Foil intact, semi-bright, tough
54	25	0.45	41	3	150	0.2	Foil intact, bright, tough

Table I—Typical plating conditions and the effect on the foils resulting from their application are shown in the table at the right.

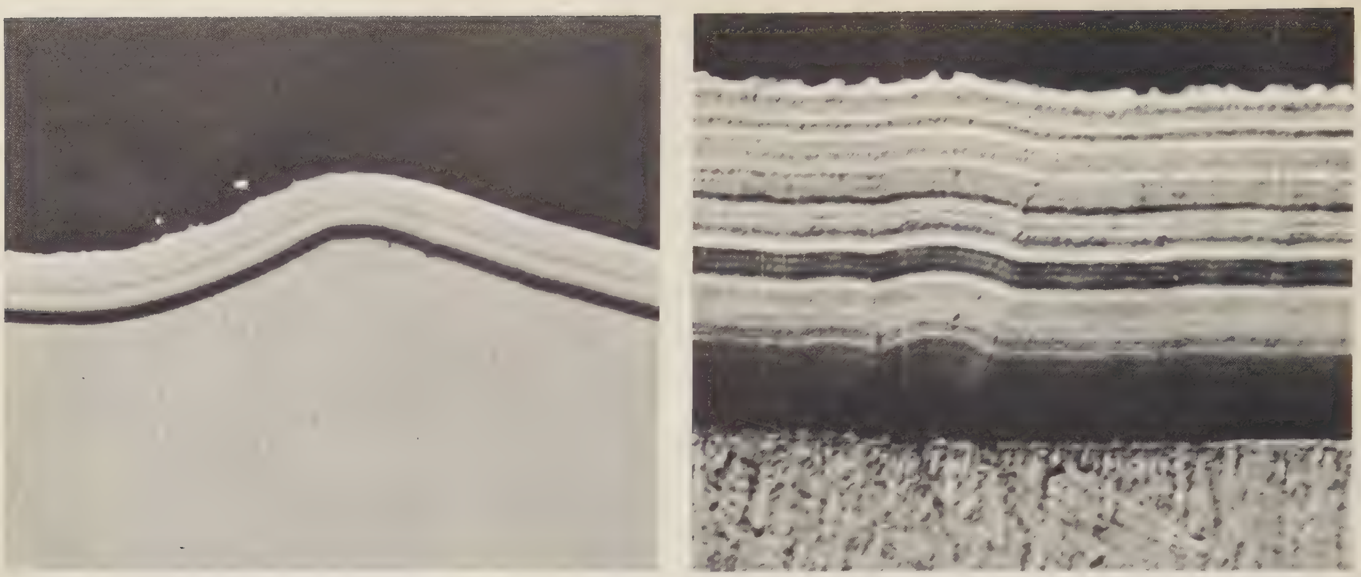

Fig. 3—Photomicrographs of a section of a precision reference specimen of surface roughness plated from a solution containing only sodium allyl sulfonate are shown here. The specimen had a peak-to-valley height of 0.002 in. It was cross section and etched in 1 to 1 nitric acid-acetic acid. The specimen was then magnified 100 times (left) and 500 times (right), as shown in these photomicrographs.

tope S-35 was one reported by Hoekstra[18]. The metathesis reaction was carried out between allyl bromide and sodium sulfite containing S-35 as the labeled atom. One-millimole amounts of each of the reactants were heated together in a closed system at 60°C for 35 hours. Excess allyl bromide was extracted by ether using a Soxhlet extractor. The product was dissolved in water to yield a solution concentration such that one milliliter contained approximately 0.003 gram of radioactive sodium allyl sulfonate. A radiochemical analysis of the final product showed a recovery of about 95 per cent of the original activity present in the sodium sulfite (Appendix A).

Plating Procedure Closely Controlled

The stock nickel solution was a Watts-type bath containing nickel sulfate, 300 grams per liter; nickel chloride, 30 grams per liter; boric acid, 30 grams per liter, and a proprietary wetting agent, 5 milliliters per liter. The pH was adjusted to 3.0. Plating was carried out in a small plastic cell in a glove box (Fig. 1). The anode used was electrolytic nickel, the current density range was from 10 to 55.5 amperes per square foot, and the plating times varied from 20 to 100 minutes depending upon the thickness of deposit desired. Due to rapid changes of pH in the small volume of solution used, frequent additions of dilute sulfuric acid were made to maintain a pH range from 2.6 to 3.5.

Since a surface consisting of peaks and recesses was desired, grooved cathodes were prepared from brass blocks (Fig. 2). To obtain foils of the plated metal, it was necessary to provide a passivated surface. Therefore, the brass cathodes were first plated with a thin deposit of nickel from a sulfamate bath and then passivated by immersion for one minute in a 0.05 per cent potassium dichromate solution.

The organic addition agent was added to the nickel stock solution in the form of radioactive sodium allyl sulfonate (one milliliter equals approximately 0.003 gram). Additional non-radioactive sodium allyl sulfonate was added to bring the total concentration within a range of 1.5 to 2 grams per liter. In some of the experiments, a second organic addition agent, N-allyl quinaldinium bromide, was added in amounts sufficient to produce concentrations from 2 to 6 milligrams per liter. All of the additions and plating procedures were carried out under radiochemically safe conditions.

At the conclusion of plating, the cathode was withdrawn from the cell and rinsed with distilled water. Then, a scalpel was used to remove the foil from the cathode block. The foil was scrubbed on both sides to remove any adhering material, rinsed with water and with alcohol, and dried under an infrared lamp to prepare it for counting and autoradiography. The data pertinent to the plating conditions and foils produced were recorded (Table I). The data were representative of the 65 plating experiments carried out

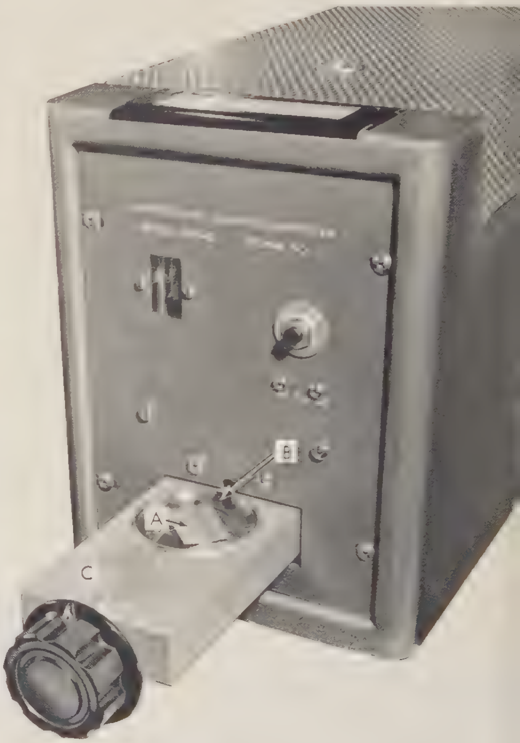

Fig. 4—Shown here is a nickel foil *A* on the sample pan *B* of a typical gas flow proportional counter. The advantage of such a counter, when counting low energy radioactivity such as S-35 emits, is its increased sensitivity which is achieved by placing the sample in the sensitive volume of the counting chamber, thereby eliminating the window such as is found in the Geiger tube. The corrugated lead foil *C* with its single slit was overlaid on the radioactive foil exposing a single peak (or valley by turning the foil over), and a count was made. Successive counts provided a profile of the areas in question. The lead foil was thick enough and big enough to screen out all of the radiation except that emanating from the area exposed by the slit.

LEAD SLIT COUNTING DATA

TOP OF FOIL			
FOIL A		FOIL B	
PEAK	RECESS	PEAK	RECESS
125	94	42	27
115	72	33	33
115	53	76	53
143	63	47	81
213	80	177	91
226	163	163	160
224	212	94	97
125	65	147	34
106	64	43	28
55	55	59	45
79	57	58	
BOTTOM OF FOIL			
FOIL A		FOIL B	
OBVERSE OF THE PEAK	OBVERSE OF THE RECESS	OBVERSE OF THE PEAK	OBVERSE OF THE RECESS
248	143	145	58
198	103	133	77
152	133	134	84
120	112	154	65
207	102	135	100
254	113	190	128
227	163	212	126
150	146	176	101
146	129	163	82
181	158	144	80
242	129	102	

Table II—Data from one test using the lead slit profile counting technique are shown in this table. Counting was done from left to right on the top of the foil, and right to left on the bottom, so that the values in the columns are matched. All values are counts per minute.

and the 55 nickel foils produced.

To check whether or not these solutions and conditions produced leveling, portions of a Precision Reference Specimen of Surface Roughness[2] with two different degrees of surface irregularities were plated under conditions identical with those just described. Duplicate specimens were plated, one in a solution containing only sodium allyl sulfonate, the other in a solution containing both sodium allyl sulfonate and N-allyl quinaldinium bromide. These specimens were cross sectioned and examined microscopically (Fig. 3). Original and final roughness measurements were made with a topographic microscope (Appendix B), and showed that leveling did occur. The solution containing both addition agents produced the greater degree of leveling.

Amount and Location of Radioactivity Studied

Two methods were used to locate and define the areas on the plated cathodes and foils which contained the radioactivity. The first of these was a counting technique.

Counting Procedures

Since the energy of the beta particles emitted by S-35 atoms was very weak, the standard Geiger tubes were not sensitive enough. To achieve satisfactory sensitivity, a gas flow proportional counter was employed (Fig. 4). This procedure provided a gross count of the activity on the top and bottom of the foils, but gave no information relative to the distribution of the radioactivity across the face of the sample. It did, however, give data which were useful in computing autoradiographic exposure times.

Several innovations were tried to give more quantitatively useful data which might augment the results of autoradiography. One of these was a profile counting technique (Fig. 4). A 0.005-in. thick piece of lead foil was corrugated to duplicate the surface of the nickel foils by pressing the lead into the grooves of one of the cathodes. A single slit, 0.002 in. wide by one in. long was cut in the center of one peak. This lead foil was then overlaid on the radioactive foil and a profile of the peaks and valleys made by successive counts on both sides of the foil (Table II).

Autoradiography

Autoradiography was the primary source of information on the distribution of the radioactivity over the surface of the foil. Autoradiography makes use of the fact that the radiation from radioactive materials causes darkening of a photographic film much the same as light. The term *auto* indicates that the radioactivity is contained within the specimen that is being examined.

Since the S-35 gave off a very weak beta ray, it was considered necessary to have the foil in direct contact with the film. Therefore, most of the foils were mechanically flattened, placed between two pieces of film, and then weighted to insure good contact. Past experience indicated that both chemical and pressure effects on the film could result from this method of exposure. To insure that everything which appeared on the final autoradiogram was due to radioactivity and not to side effects, foils containing no radioactivity were exposed under identical conditions to check possible chemical interaction and the effects of pressure. These tests showed no influence of side effects. Although several types of film were used, the autoradiograms illustrated in this paper were made on Type AA film.

Composite data on the counting and autoradiographic exposures (Table III), and representative autoradiograms of the top and bottom surfaces (Fig. 5), revealed the location of radioactivity in the depositions. In addition to visual inspection, densitometric readings on a recording densitometer were made and were recorded below each autoradiogram (Fig. 5).

Most of the foils were mechanically flattened during autoradiography to obviate the differences in distance between the peaks and recesses and the film. Some of the foils were quite brittle, making the flattening process very difficult. Therefore, a check was made with a representative foil to determine if the mechanical flattening gave any advantage, either for the autoradiogram or for the subsequent

COUNTING DATA AND AUTORADIOGRAPHY

FOIL NO.	COUNTS (CPM PER CM^2)	TYPE OF FILM	EXPOSURE TIME (HOURS)	RESULTS		
				IMAGE	DETAIL	BACKGROUND
21	T-12*	KK	833	Fair	Poor	Heavy
	B-10*	KK	833	Fair	Poor	Heavy
25	T-22	KK	833	Good	Fair	Heavy
	B-30	KK	833	Good	Fair	Heavy
26	T-15	KK	1268	Poor	Poor	Heavy
	B-13	KK	1268	Poor	Poor	Heavy
31	T-1830	K	22	Good	Fair	Heavy
		AA	67	Good	Good	Light
	B-2320	K	22	Good	Good	Heavy
		AA	67	Excellent	Excellent	Light
34	T-850	AA	141	Good	Fair	Light
	B-895	AA	141	Excellent	Good	Light
36	—	AA	66	Good	Good	Light
	B-2231	AA	66	Good	Good	Light
38	T-901	KK	18	Fair	Fair	Heavy
		AA	48	Good	Good	Light
		AA	146	Excellent	Excellent	Light
	B-2116	KK	18	Good	Good	Heavy
		AA	48	Good	Good	Light
		AA	67	Excellent	Excellent	Light
41	T-736	AA	67	Poor	Poor	Light
	B-1656	AA	67	Good	Fair	Light
51	T-585	AA	67	Excellent	Excellent	Light
	B-1434	AA	67	Excellent	Excellent	Light
54	T-804	AA	67	Good	Good	Light
	B-1221	AA	67	Excellent	Excellent	Light

*T—top of foil; B—bottom of foil

Film Processing Conditions: Temperature, 19°—20° C (67°—69° F)
Development time, 4—6 minutes
Developed emulsions on both sides of film

Table III—Composite data on the counting and autoradiographic exposures are given in this table.

densitometer trace (Fig. 6).

With the data obtained and the observations made, it was possible to draw some conclusions about the phenomenon being considered.

A Leveling Theory Confirmed

An examination of the autoradiograms (Fig. 5) shows a greater darkening on those portions of the film which were irradiated by the peaks of the foils. In those autoradiograms labeled *Top*, the difference in density of the lines produced by peaks and recesses is evident, but there also is present a greater smearing of radioactivity than is apparent on the corresponding *Bottom* autoradiograms. The concentration of activity in both instances, however, is much higher on the peaks than in the recesses. This is especially true with the *Bottom* autoradiograms, which show that the activity is concentrated on the obverse of the *Top* peaks. This differential darkening of the films means that there is greater radioactivity emanating from the peaks than from the recesses.

The slit counting data for radioactivity on the peaks and in the recesses (Table II) serve as quantitative confirmation of the results shown visually by the autoradiograms. Likewise, the densitometer traces made from the autoradiograms show quantitatively the distribution of radioactivity over the entire surface. The concentration of activity is highest on the peaks of the *Top* autoradiograms and on the obverse of the peaks on the *Bottom* autoradiograms. These traces also indicate the manner in which radioactivity increases from a minimum at the bottom of a recess to the maximum at a peak.

In explanation of these results, it is apparent that the ratio of radioactive material (sodium allyl sulfonate or a reduction product containing the S-35) to deposited metal is greater on the peaks than in the recesses. Consequently, there is less self-absorption of the radioactivity by the thinner nickel metal on the peaks and, therefore, a greater darkening of the film occurs. This explanation is consistent with the fact that in leveling, less metal is deposited on the peaks and more metal is deposited in the recesses of an irregular surface. In order to initiate the leveling process, the addition agent first must be concentrated preferentially on the peaks.

The autoradiograms and the slit counting data appear to confirm the assumption of a preferential adsorption or codeposition of the addition agent on the peaks. Actually, these results, as well as those recorded in the literature, show only that the agent is concentrated at the peak area. The mechanism of this concentrating action, possibly a chemi-sorption or cataphoretic phenomenon, has not yet been demonstrated satisfactorily. While some investigators[7, 14] have shown that certain addition agents are apparently deposited with the metal in an unchanged or un-reduced state, the work of Hoekstra[18] and Vanderkooi[15] strongly indicates, in the case of sodium allyl sulfonate, that its reduction product, sulfide ion, is present in the electrodeposited nickel metal. The present work, with this same addition agent, shows only that the labeled S-35 atom is located in the deposit, since no attempt was made to distinguish between the possible presence of the sulfonate or the sulfide.

With the type of bath employed in this study, the leveling process is accompanied by the formation of laminations (references 2, 4, 6, 9, 11, 15, 18, and 19), which appear as light and dark bands. Several investigators[6, 15, 18] have speculated that the dark bands contain sulfur, probably in the form of sulfide. It has been proposed by Vanderkooi[15] that the dark bands are formed by the reaction between nickel and the reduction product of the sodium allyl sulfonate, while the light bands are nickel metal. In order to account for the formation of these laminations as they accompany the leveling process, it is convenient to assume that both phenomena start with a preferential adsorption of the addition agent on the peaks. It would appear (from an inspection of Fig. 3) that the formation of the laminations is some type of cyclic process, wherein alternate layers of metal, and the addition agent or its reduction product, are deposited. The start of this cyclic process and the inhibition of metal deposition on the peaks can be explained by an assumption of preferential adsorption of addition agent.

Summary

The objectives of this study have been fulfilled. An organic addition agent, sodium allyl sulfonate, containing radioactive S-35 has been synthesized. This addition agent has been used as a component in a bright nickel plating bath to produce leveling nickel deposits. A radiochemical technique has been developed to locate radioactivity in the deposited metal. Autoradiograms and counting data from the produced nickel foils show that the radioactive addition agent, or its reduction products, is preferentially adsorbed or co-deposited on the high points of an irregular surface. On the basis of this evidence, confirmation is obtained for a theory which accounts partially for leveling action in the type of bright and leveling nickel solutions considered in this study.

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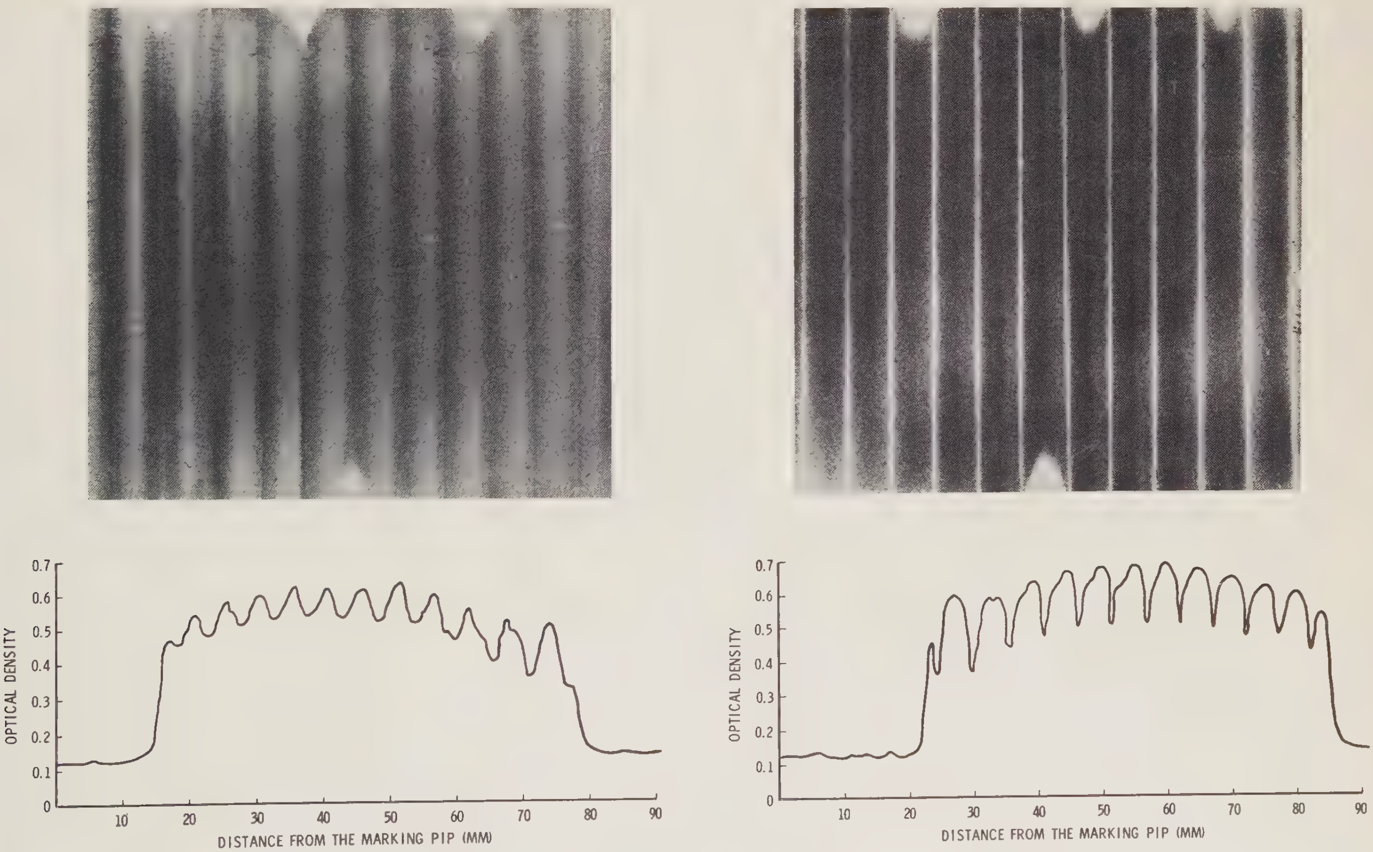

Fig. 5—Representative autoradiograms of the *Top* (left) and *Bottom* (right) of a foil are shown here. These reproductions are positives which are identical with the original autoradiograms. The dark areas indicate the regions of the foils which contain radioactivity. Since it was necessary to make an intermediate negative to achieve this reproduction, some detail has been sacrificed. All of the notches or holes cut into the foils and visible in the autoradiograms were cut for identification purposes. This system of notching not only allowed identification of the individual foils, but also precisely located the peaks and recesses on a given foil. Since the recording densitometer produced a marking pip each 0.5 millimeter, it was possible, by placing a mark near the edge of the autoradiogram, to make an accurate measure of the distances from the edge. By calibrating the instrument prior to use with a standard step wedge, the densities recorded were the actual densities from exposure to radioactivity when all possible variables in film processing were kept constant.

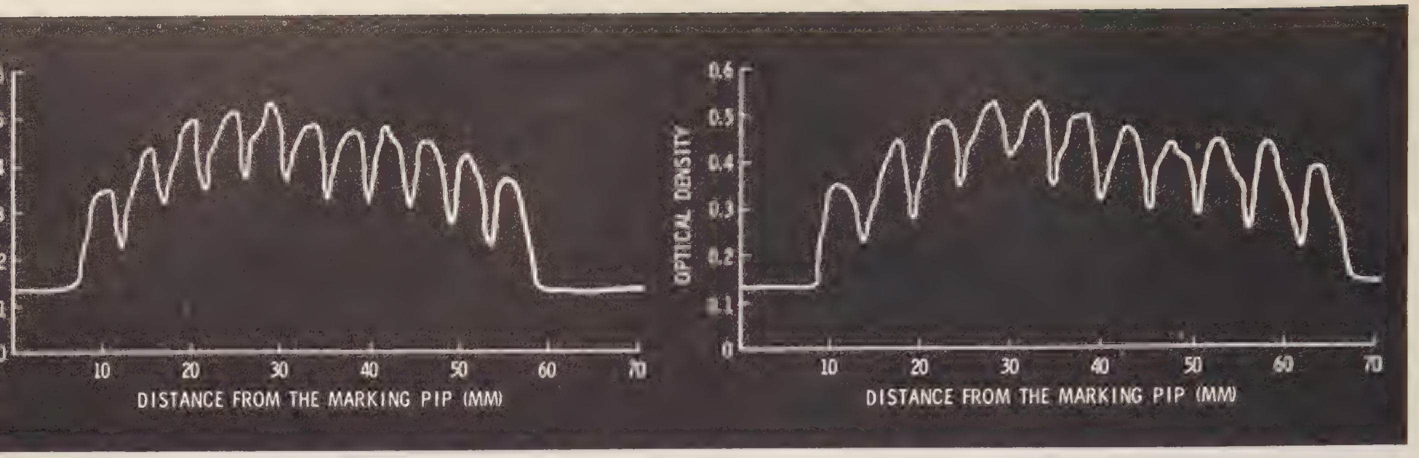

Fig 6—To determine whether the mechanical flattening of a foil had any significant effect on its autoradiogram, a comparative test was run on a foil. After removal from the cathode, an autoradiogram was made from a foil. The foil was then flattened and another autoradiogram obtained on the same type of film exposed for the same length of time and under the same conditions. The densitometer traces of the autoradiograms before (left) and after (right) the foil was flattened indicated that there was no advantage in mechanically flattening the foil. There were no significant differences between the autoradiograms.

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Appendices

APPENDIX A

Recovery Data and Calculations

The radioactive sample originally was 11.0 millicuries of S-35 activity in 108 milligrams of Na_2SO_3 or 12.4 millicuries per millimole on March 17, 1958. As a result of adding an additional 350 milligrams of inert Na_2SO_3, the specific activity then became 3.42 millicuries per millimole. This sample was dissolved in 2 milliliters of H_2O to give 1 millimole per 0.55 milliliter of solution.

Since the final reaction product was not dried and weighed but rather diluted to 50 milliliters, information on the recovery of the organic preparation was desired to insure that sufficient primary brightener would be added to the final plating bath. With radioactive material present, it was a relatively simple process to determine the activity concentration in the final solution and from that infer the amount of sodium allyl sulfonate recovered.

The activity concentration in the original solution was too high for counting so it was necessary to take an aliquot of the original solution and make a secondary dilution. The counting samples were then taken from this dilution. These counting samples were pipetted, using micropipettes, onto stainless steel planchets and then dried under an infrared lamp prior to counting. The counting was done in a gas flow proportional counter using a 90 per cent argon and 10 per cent methane counting gas.

In this type of counting system, the sample is enclosed in the active volume of the counting chamber. The theoretical efficiency of this chamber is 50 per cent. Since it encompasses half a sphere, it is frequently called a 2π counter. The actual efficiency is somewhat higher than 50 per cent due to backscatter. This term is defined as the reflection into the detector of particles whose original direction was such that they would not have passed through the sensitive volume of the chamber or tube. For this particular counting setup the backscatter correction is 1.32 for stainless steel. This gives an overall counting efficiency of 66 per cent. This is considerably better than the efficiency of about five per cent for a Geiger tube and is one of the principal reasons for choosing the proportional counter.

Several dilutions from the original 50-milliliter stock solution of sodium allyl sulfonate were made, but none yielded consistent results. Finally, it was determined that these inconsistencies were due to self-absorption within the sample. If a beta source had any volume at all, whether liquid or solid, there would be some absorption of the emitted radiation by the source itself. This was particularly true in the low energy range emitted by S-35 (0.167 Mev). Enough of the inert sodium allyl sulfonate precipitated out of the solution on drying to block out part of the S-35 and give inaccurate data. Likewise, the dilute acid rinse given the micropipettes while preparing the counting samples caused some of the metal planchet to dissolve which formed more salts upon drying. This contributed further to the self-absorption. To overcome these difficulties, a smaller dilution was made, smaller samples were pipetted, and only water was used to rinse the micropipettes.

As a result of these precautions, the following dilution was used for counting:

Original stock solution	50 milliliters
Sample for dilution	100 lambda*
Final dilution	50 milliliters
Date counted	June 10, 1958

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*1 lambda $=1/1{,}000$ milliliter. Symbol is λ.

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* * *

RECOVERY COUNTING DATA

SAMPLE NUMBER	VOLUME OF SAMPLE	NET CPM*	CPM PER λ
1	25λ	2,606	104.2
2	50λ	4,852	97.0
3	50λ	4,311	86.0
4	50λ	4,927	98.5
5	50λ	4,771	95.4
*Counts per minute		AVERAGE = 96.2	

The following calculations, based upon the dilution and counting data given in the preceding table, are designed to show the amount of recovery of the organic preparation by comparing the activity present before and after plating.

The first four calculations produce the activity at the time of counting. The remaining calculations derive the activity at time zero, and determine the per cent of recovery.

$$[(96.2\ \mathit{cpm\ per}\ \lambda)\ (1{,}000\ \lambda\ \mathit{per\ ml})\ (50\ \mathit{ml})] = 4.81(10^6)\ \mathit{cpm\ per}\ 100\lambda\ \mathit{of\ original\ solution} \qquad (1)$$

$$[(4.81(10^6)\ \mathit{cpm\ per}\ 100\lambda)\ (10)] = 4.81(10^7)\ \mathit{cpm\ per\ ml\ of\ original\ stock} \qquad (2)$$

$$[(4.81(10^7)\ \mathit{cpm\ per\ ml})\ (50\ \mathit{ml})] = 2.40(10^9)\ \mathit{cpm\ in\ the\ original\ solution} \qquad (3)$$

$$\frac{2.40(10^9)\ \mathit{cpm}}{(0.66\ \mathit{efficiency})\ (2.22)\ (10^9)\ \mathit{dpm\ per\ mc}} = 1.64\ \mathit{mc\ per\ mm} \qquad (4)$$

where

dpm = disintegrations per minute

mc = millicuries

mm = millimoles.

$$A = A_o e^{-\lambda t} \qquad (5)$$

where

A = activity at time of counting = 1.64 mc per mm (June 10, 1958)

A_o = activity at time zero (March 17, 1958)

t = time since time zero = 85 days

$\lambda = 0.693\ t_{\frac{1}{2}}$, where $t_{\frac{1}{2}}$ = half life = 87 days for S-35.

Therefore,

$$1.64\ \text{mc per mm} = A_o e^{-\left[\frac{(0.693)\ (85)}{87}\right]}$$

$$1.64\ \text{mc per mm} = A_o e^{-0.667}$$

$$A_o = \frac{1.64}{0.508} = 3.23\ \text{mc per mm} \pm 10\ \text{per cent.}$$

Since the specific activity of the original solution was 3.42 mc per mm, the recovery, therefore, is equal to

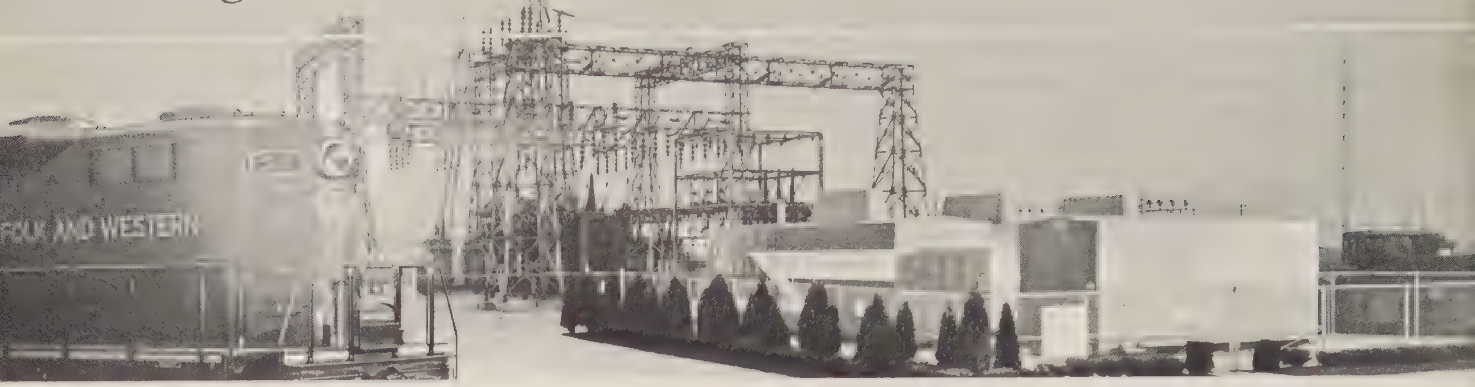
$$\frac{3.23}{3.42}\ (100) = 95 \pm 10\ \text{per cent.}$$

APPENDIX B

Topographic Microscope

The topographic microscope, recently developed at the General Motors Research Laboratories, may be used to measure the depth of depressions in metal surfaces as well as the thickness of deposited metals. [For details, see R. L. Saur, *Review of Scientific Instruments*, Vol. 29, p. 1,023 (1958).]

A New Product Design: Evolution of a 6,000-kw Generating Plant for Peaking and Reserve Capacity



Electrical power generation for public use includes the problem of providing for the so-called *peak demand*—those unusual demands for current which may occur for only small parts of the day or only on certain days of the week. How the peak demand is handled is a matter of economics in the power supplying organization. One solution is a local peaking plant as opposed to enlarged capacities of the central station, power lines, and sub-stations. To serve as a peaking plant, a new, transportable, Diesel-powered electrical generating plant has been developed by Electro-Motive Division engineers working with the aid of recommendations from electrical utility companies. The design task represented the application of existing concepts (gained from Electro-Motive's experience with smaller, mobile power plants and with Diesel-electric locomotives) plus the application of some new concepts to meet the overall objective. For example, typical design criteria which the peaking plant ultimately met were: 6,000-kw capability, low installed cost per kw, quietness, portability, reliable, unattended operation, and fast starting.

The concept in designing the new 6,000-kw power plant was primarily to provide a new electrical generating plant to aid American electrical utilities in meeting vexatious and costly problems growing out of the rapid increase of consumption of electricity. Unusual demands for current for only small parts of the day or only on certain days of the week must be met in both old and new areas, under modern conditions of living and industrial operation. To meet these part time demands by costly additions to central station capacity, enlargement of capacity of long power lines and substation equipment is uneconomic. The so-called peaking plant, which is located close to the neighborhood where the unusual demand exists, can be a cost saver for this service as well as providing stand-by capacity for emergencies.

The 6,000-kw, Diesel-powered plant has been developed out of the experience of Electro-Motive Division in the manufacture and observation of more than 100 mobile power plants of 500-kw and 1,000-kw capacity (first introduced in 1955), and out of a quarter-century's experience in building Diesel-electric locomotives. Most of the mobile plant installations, however, were used for base load in specialized situations rather than as peak skimmers. As a result of continuing studies and discussions with some electrical utility companies, a set of new requirements for peaking plant service evolved. Studies were made of the economics of the peaking plant in certain utility systems which resulted in some general specifications for this concept.

Design Criteria Established

This design project, therefore, started with these specifications:

(a) *Higher capacity:* minimum capacity of the plant should be 5,000-kw
(b) *Lower cost:* cost per kilowatt of installation and operation should be substantially lower than the cost of installing a steam plant facility for this service
(c) *Ease of transportation:* the plant should be of minimum size and weight to facilitate delivery, initial installation, or relocation
(d) *Unattended operation:* functioning of the plant should be automatic, requiring no operator, and should be completely protected for fail-safe operation
(e) *Reliability:* ready availability and reliable operation should be assured with simplified control systems and minimum maintenance requirements
(f) *Quietness:* the plant should be clean, quiet, and presentable—a "good neighbor" in the community
(g) *Fast starting:* the plant must start and be on the line in a minimum of time to fulfill "spinning reserve" needs. (A goal of 90 seconds was selected.)

These requirements, of course, presented a rather challenging task. Fortunately, the locomotive manufacturing capacity and experience with smaller mobile power plants simplified the design approach for many of the components which could be used in the new peaking plant. However, several new problems were present (larger capacity, minimum size, lower cost, quieter operation); thus, all of the design elements had to be brought together to result in an acceptable power plant for peaking service.

Electro-Motive Division had previously designed and built a 500-kw mobile power plant as a truck-trailer unit for movement over highways and a 1,000-kw power plant as a railway car unit for movement over rails (Fig. 1). Multiple units could be used to supply greater power

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The engineer's task: greater capacity and lower cost per kw than former designs

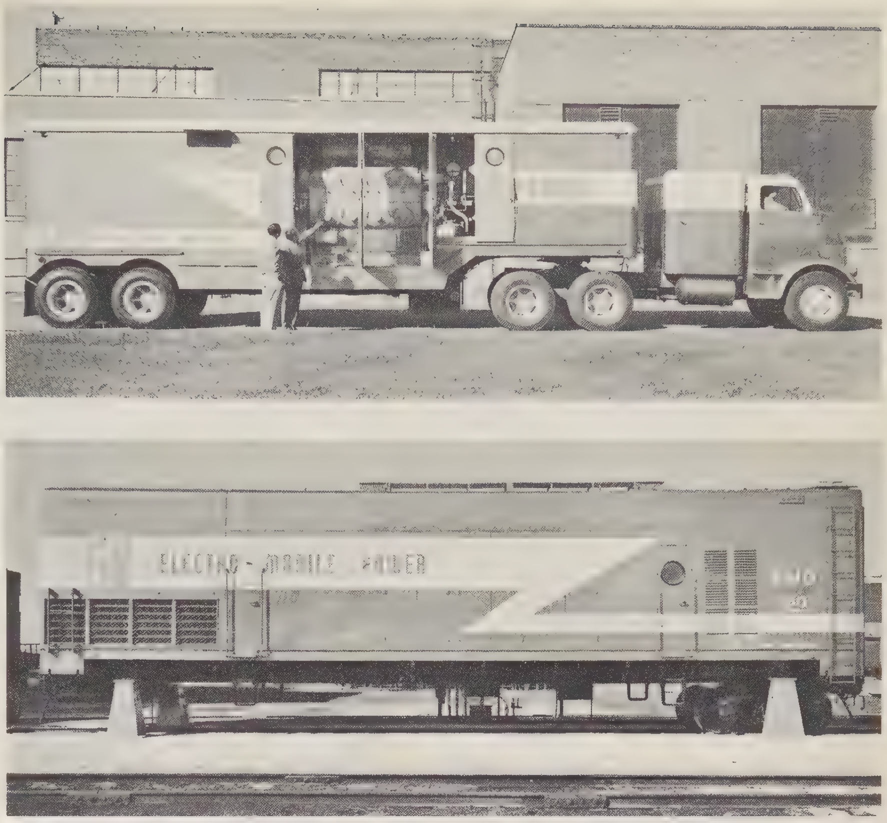


Fig. 1—Previous versions of the Electro-Motive mobile power plants are the 500-kw plant (top) intended for movement over highways, and the 1,000-kw plant (bottom) for movement over railroads. Since introduction of these power plants in 1955, more than 100 units have been placed in service, primarily for base-load requirements, in various parts of the United States, Central America, and overseas locations. These plants contained all necessary equipment such as fuel supply, engine, generator, and control system.

outputs. Studies of the costs involved, in cooperation with utilities, showed, however, that simply adding more of these existing plants to an installation would be too expensive for peaking service. Thus, some new solution was needed to meet the design specifications. After further studies and reviews among Electro-Motive management, sales, engineering and manufacturing personnel, some new design concepts evolved.

One of the first of these was the elimination of the rail car idea. A review of various installations of rail car plants, the cost of applying railroad equipment to the plant, and the moving problems involved showed that a base-mounted, transportable plant had definite advantages. These advantages included lower cost and improved mobility through reductions in weight and overall size of the components.

Another new design concept was the use of separate generating units and a single control station to minimize duplication of control equipment. The existing 500-kw and 1,000-kw power plants housed the engine-generator equipment and controls in a single enclosure. In considering a multiple unit application, therefore, studies of the installation cost per kw of electrical equipment showed obvious economic advantages. Duplication of special equipment such as batteries (for engine starting), battery charger, meters, synchronizing equipment, transformers, and protective relays could be eliminated by using a separate control facility. The resulting concept, therefore, was the use of three generating components and one control component to constitute the complete power plant.

A third major design concept involved making the power plant completely automatic and providing only those manual controls necessary for periodic inspections and maintenance. The important effect of such an automatic feature on the operating economies of a power plant used for peaking and/or emergency reserve are readily apparent. Designing the power plant for automatic, unattended operation directed special emphasis to the factors of reliability, safety, and minimum maintenance. As a result numerous component and system improvements were developed with a view to fulfilling these objectives. These included such items as a newly designed static-type excitation system; fail-safe circuit design; use of a long life, disposable, car body air intake filter; and use of a reserve lubricating oil supply tank for the engine.

Design Approach Used 2,000-kw Turbocharged Diesel Unit

Two steps were taken in the evolution of the design of the generating units for this new power plant. The first was to increase the rating of the Diesel-electric generating plant from 1,000-kw at 720 rpm to 1,400-kw at 900 rpm. This plant incorporated an Electro-Motive, normally-aspirated Diesel engine (567C) with certain modifications including an increased compression ratio of 18 to 1. Three of these generating plants at a designated rating of 1,400-kw would result in a total plant capacity of only 4,200-kw, which was below the design minimum. A fourth unit could be added to raise the capacity to 5,600-kw.

The second step was to incorporate the turbocharged Diesel engine with the required accessories to develop 2,000-kw each.

Fortunately, engineering development of a turbocharged engine for locomotive application had been under way for some time by Electro-Motive engineers. Thus, the progress from this work was available for the development of the new 2,000-kw power unit. The result was the 6,000-kw power plant consisting of three, 2,000-kw generator units and a separate control unit (Fig. 2).

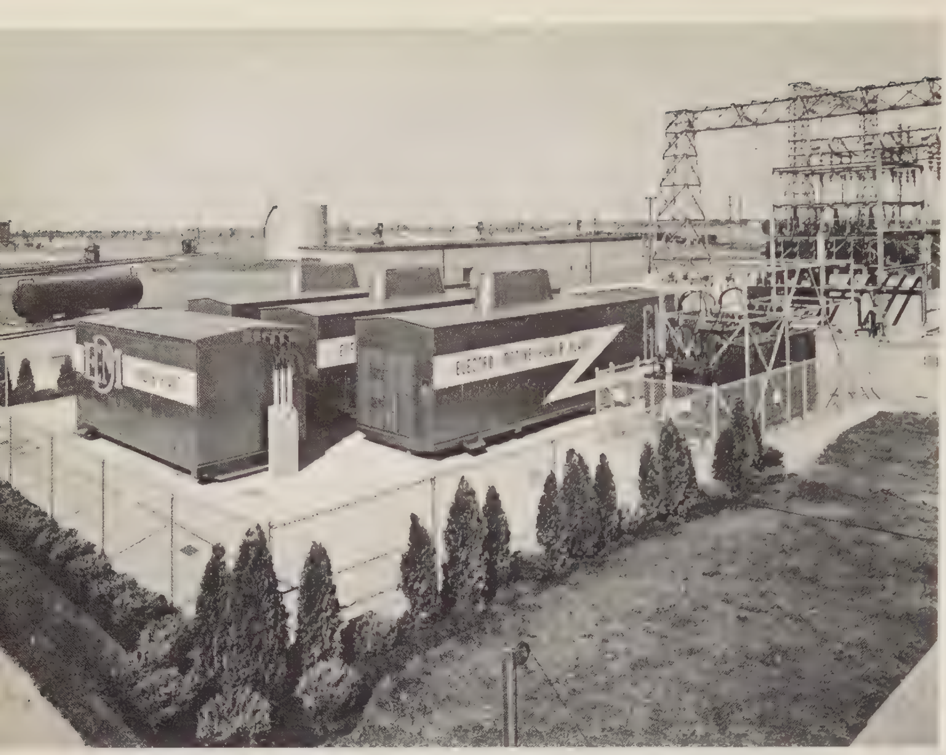


Fig. 2—The design concept of the new 6,000-kw peaking power plant resulted in the arrangement shown at the left. This installation was made on Electro-Motive property to study all procedures that would be encountered in a typical installation by a utility company. The three engine-generator units are connected by a common control-switchgear station, from which power is delivered to the utility's transformer and distribution system. The sheet metal enclosures are insulated for sound deadening to contribute to the "good neighbor" requirement.

A prototype plant of 4,200-kw was built and installed on a representative site location to study the installation steps and costs involved from the time the power plant left the manufacturer until it was ready to supply electrical power to the user's system.

New Design Features Used in Engine-Generator Units

A discussion of various components of the power plant will illustrate how the final design satisfied the established specifications and how some of the design problems were solved.

Each of the three generator units of the plant is contained in a steel, sound-insulated enclosure which is 38 ft long, 10 ft, 6 in. wide and 11 ft, 4 in. high. Each unit weighs about 103,000 lb without supplies such as oil and water. These physical characteristics demonstrate that the unit can be easily transported, after complete assembly, on a standard railroad flat car, and it can be transferred to regular lowboy type highway trailers. The fourth unit of the power plant—the control unit—has the same width and height as a generator unit but is only 24 ft long and weighs about 38,000 lb. For comparison, the former 1,000-kw rail car mobile power plant was 50 ft long, 15 ft high, and weighed about 150,000 lb with trucks.

The concept of separate generating and control components, with the resulting reductions in weight and size, contributes to the overall lower cost per kw

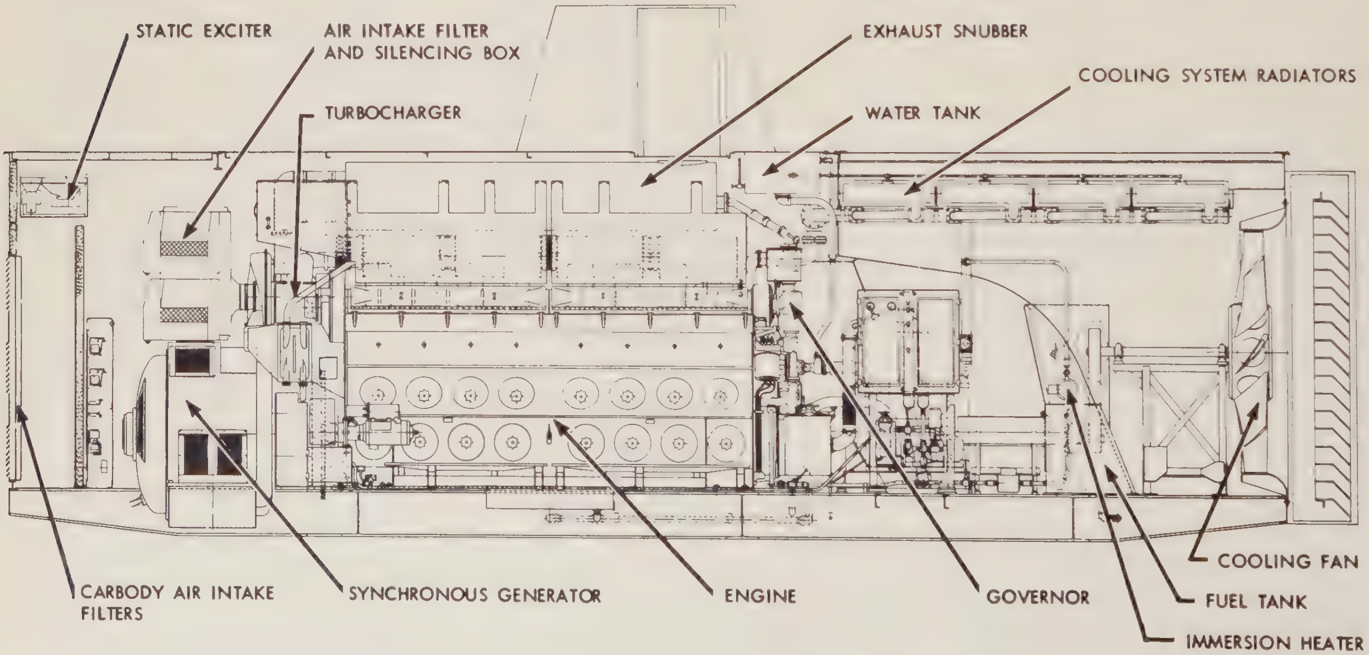


Fig. 3—Design features and arrangement of the principal components are shown in this view of the engine-generator unit. Hatches and access doors provide for convenient inspection and maintenance. Electrical connections, grounding pads, and fuel piping connections are at the bottom of the unit.

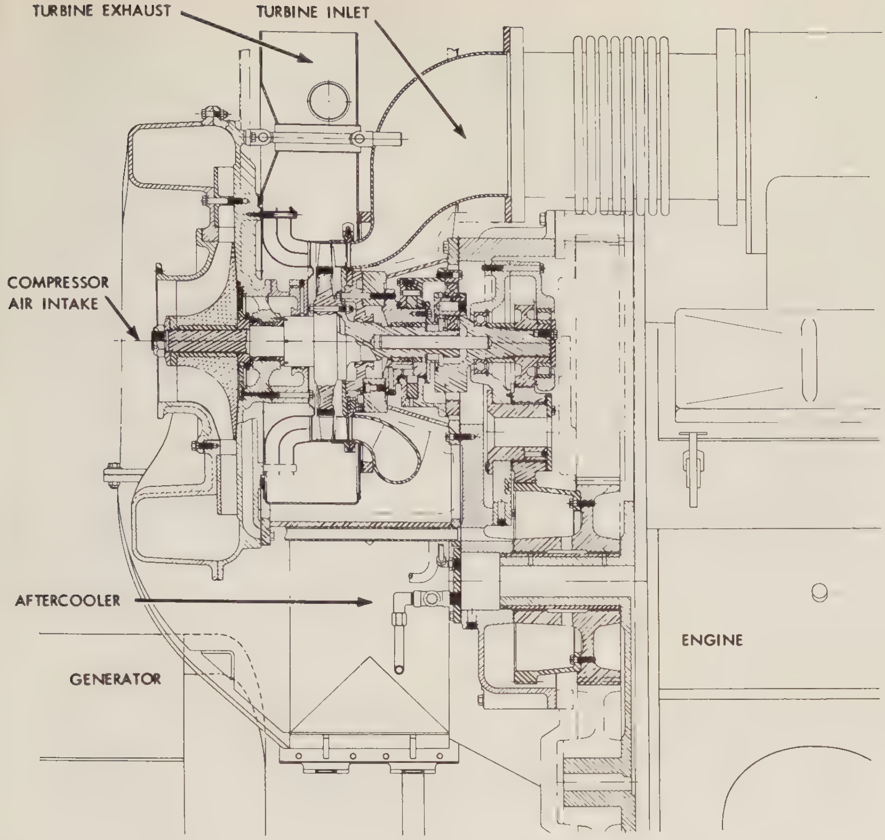


Fig. 4—The location of the turbocharger and its principal components is illustrated in this cross-sectional view. The turbocharger is driven by the engine through a gear train during operating periods when the exhaust heat is not sufficient to drive the turbine (for example: periods of starting, rapid acceleration, and light load operation). At about two-thirds of full load (1,350-kw), an overrunning clutch disengages the gear train and the engine exhaust drives the turbocharger. Engine exhaust from the manifold is directed against the single-stage turbine blades and expanded down to atmospheric pressure. The turbine drives the centrifugal compressor at the outboard end of the turbine shaft. The compressor draws fresh air through filters (not shown) and delivers the air through two ducts to the two sides of the engine air box. An aftercooler is located in each of these ducts to reduce the temperature of the air entering the engine.

for transporting and installing the new power plant. The handling of each component would be comparable to the procedure experienced with many transformer installations at utilities.

Each generating unit contains such basic components as the prime mover, alternator, cooling system, lubricating oil system, and fuel system (Fig. 3).

Turbocharged Diesel Engine

The prime mover is a 16-cylinder Diesel engine (designated 567D), similar to the type built by Electro-Motive for many years for locomotive service. The engine is turbocharged and has a 14.5 compression ratio. The turbocharger, designed especially for this engine, has a single stage reaction type turbine and centrifugal compressor (Fig. 4). The turbocharger is driven by the engine through a gear train during the periods of starting, light load operation, and rapid acceleration. At about two-thirds of full load (1,350-kw) an overrunning clutch disengages the turbocharger from the gear train. At this load point and above, the exhaust heat energy is sufficient to drive the turbine without help from the engine. This method of driving the turbocharger eliminates the need for conventional blowers.

The starting means for the engine was one of the design changes introduced into the new generating unit. The method of engaging the starting motor pinion with the flywheel ring gear was changed to the type of drive which engages the gears before the starting motor rotates—as opposed to another type in which the pinion is engaged after it is rotating. Electro-Motive engineers designed a solenoid for engaging this type of starter. The advantages of this arrangement are the elimination of high shock loads on the gears and motor bracket, and greater reliability.

Another design change was the use of an engine governor incorporating a dual speed range. During normal operation, that is, in non-emergency situations, the engine is started and idled for one minute to build up oil and water pressures before raising to synchronous speed. A three-minute idle speed also is used on shutdown to stabilize engine temperatures. For fast starting, controlled acceleration to synchronous speed is accomplished in seven seconds. With this governor, the engine speed can be changed readily from idle range to the 60-cycle speed range (900 rpm) without the time delay of waiting for a synchronizing motor to operate the speeder spring. The governor utilizes two solenoids, at idle speed and 60-cycle speed, to accomplish the dual speed range control. An improved type of synchronizing motor is used to match the alternator frequency to the line frequency by making minor variations in engine speed when synchronizing.

The air filters for engine combustion air are the oil bath panel type which, in the typical peaking service of this power plant, would require maintenance only about twice a year.

A specially designed muffler is mounted inside each generating unit of the power plant.

An exhaust aspirator is mounted on the roof and extends four ft above the roof line. The aspirator exhausts engine room air from above the engine and keeps the engine room temperature at an acceptable level. Metal shields prevent rain and snow from entering the exhuast muffler and the engine room during shutdown periods.

Cooling System

The engine cooling system consists essentially of the radiator assembly, a seven-ft engine driven fan, and an automatic by-pass valve for water temperature control. The system is pressurized (1/2 lb) to minimize evaporation.

Two engine driven pumps are used to circulate the cooling water continuously. The water connection between the oil cooler and the water pump includes an ejector, or aspirator, to provide positive pressure to the suction side of the pump and reduce the possibility of cavitation.

Lubricating Oil System

The engine lubricating oil system incorporates a number of Electro-Motive design features used both in the previous mobile power plant designs and in loco-

FREQUENCY (CYCLES PER SECOND)	60
KW	2,000
KVA	2,500
VOLTAGE	2,400/4,160
CURRENT	347/601
POWER FACTOR	0.8
RPM	900
ARMATURE DATA	
GAP DIAMETER	42.5 IN.
TOTAL CORE LENGTH	21.0 IN.
NUMBER OF SLOTS	90
RESISTANCE AT 75°C	0.0464
REACTANCES (PER UNIT)	
DIRECT-AXIS SYNCHRONOUS REACTANCE X_d	1.28
QUADRATURE AXIS SYNCHRONOUS REACTANCE X_q	0.77
DIRECT-AXIS TRANSIENT REACTANCE $X_{d'}$	0.336
DIRECT-AXIS SUBTRANSIENT REACTANCE $X_{d''}$	0.217
NEGATIVE SEQUENCE REACTANCE X_2	0.169
ZERO SEQUENCE REACTANCE X_o	0.085
TIME CONSTANTS (SECONDS AT 75°C)	
DIRECT-AXIS TRANSIENT OPEN CIRCUIT $T_{do'}$	4.34
DIRECT-AXIS SUBTRANSIENT SHORT CIRCUIT $T_{d''}$	0.017
DIRECT-AXIS TRANSIENT SHORT CIRCUIT $T_{d'}$	0.654
SHORT CIRCUIT RATIO	0.85
BALANCED TIF	14
REGULATION AT RATED LOAD	34.8%
SYNCHRONIZING COEFFICIENT (KW PER RADIAN)	
FULL LOAD	5,170
NO LOAD	3,250
AIR GAP	0.400
FIELD DATA	
NUMBER OF POLES	8
RESISTANCE AT 75°C	1.292
EXCITATION (NO LOAD AMPERES)	39.2
EXCITATION (RATED LOAD AMPERES)	80.0
EFFICIENCY	
RATED KVA AT 80% POWER FACTOR	97.1%
OVERLOAD CAPABILITY	10% CONTINUOUS
WEIGHT (TOTAL LB)	18,100
STATOR	9,000
ROTOR	8,100
END HOUSING AND BEARING	1,000
WR^2 (LB PER FT^2)	12,830

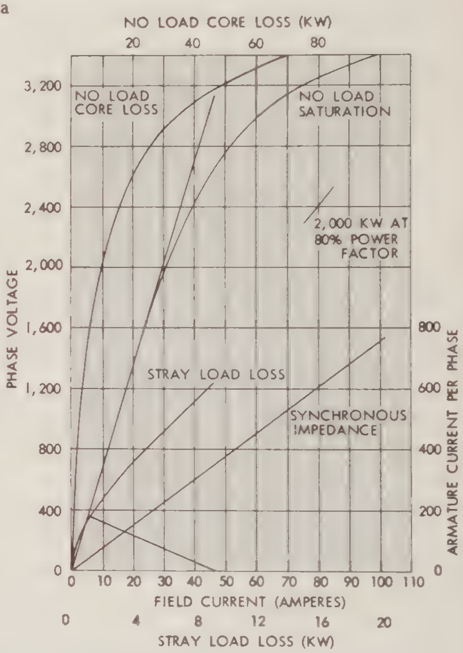


Fig. 5—Tests on the Electro-Motive designed, synchronous generator resulted in the performance data shown in the accompanying table (top) and characteristic curves (right).

motive designs. The scavenging oil is piped through an oil filter and through the oil cooler which consists of two extended surface, cooler elements. The oil discharge from the cooler is returned to the engine strainer box.

To adapt the lubricating oil system to operation of the new 2,000-kw generating unit, the engine-driven scavenging pump speed and size were increased. The lubricating oil system includes an extra oil supply tank to assure an ample oil supply for extended periods without attention, and high capacity oil filter elements.

Immersion Heaters

To provide for the fast starting requirements it is necessary to maintain engine operating temperatures in the cooling water and lubricating oil. This is done by the use of an electric immersion heater. Each generating unit is equipped with a 15-kw heater installed in a small tank mounted on top of an auxiliary fuel tank. Each heater is thermostatically controlled to maintain its outlet water temperature at 150°F. This water is circulated through the engine and oil heat exchanger by means of a magnetic circulator. A motor-driven oil circulating pump circulates oil from the engine oil pan through the oil cooler and back to the engine strainer box.

Fuel Supply System

The fuel supply system for the engine-generator unit can be considered in two parts:

(a) Supply and transfer system from a main storage tank to auxiliary tanks in the three generating units

(b) Supply system from each auxiliary tank to the engine.

The first part (a) consists of two motor-driven fuel pumps which transfer the fuel from the main storage tank to one auxiliary tank. The fuel flows to the remaining two auxiliary tanks by gravity. Fuel level switches and safety controls are provided for the completely automatic operation of the fuel supply system.

The second part of the system (b) consists of an auxiliary tank in the generating unit which provides a positive head on the suction side of the engine fuel supply pump and eliminates the need for a fuel priming pump, used on previous mobile power plants.

Synchronous Generator

The synchronous generator, designed and built by Electro-Motive, is a single bearing, salient pole, 3-phase, 60-cycle generator rated at 2,500 kva, 2400/4160 volts (Fig. 5). The rotor is directly connected to the engine crankshaft through a thin disc, flexible coupling and supported at the outboard end by a single, sealed, grease lubricated, self-aligning, spherical roller bearing.

The outer race of the bearing is insulated from the housing by a phenolic bushing. The bearing housing is supported and located by a dished steel plate end bell which is attached to the generator frame (Fig. 6).

The generator windings are insulated with Class H silicone rubber on the stator coils and Class B epoxy resin on the field winding. The silicone and epoxy systems offer the following advantages over conventional systems:

- Maximum overload protection
- Maximum life and reliability in spite of overloads and high ambients
- Reduced maintenance costs
- Greater output per pound
- No fire hazard caused by failure of conventional systems

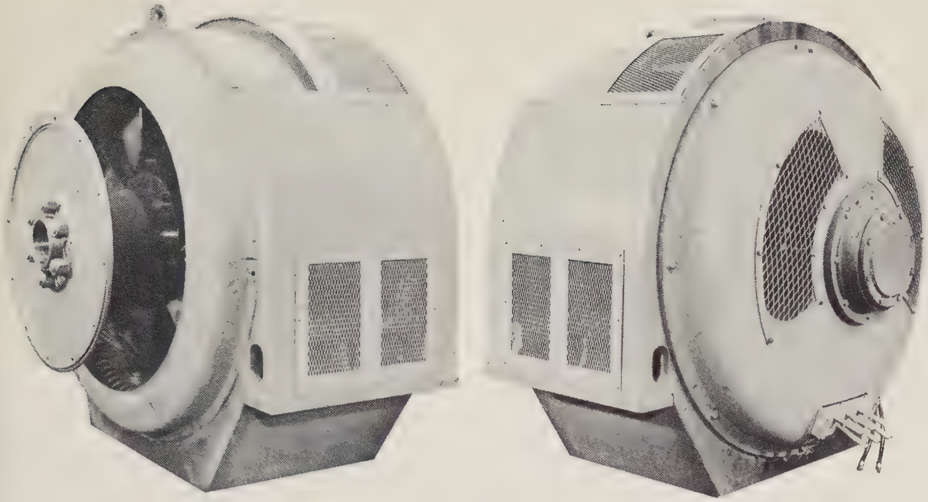


Fig. 6—The single end-bearing mounting, the flexible coupling, and ventilating features are shown in these views of the 2,000-kw synchronous generator designed for peaking and reserve plant service.

- High moisture and fungus resistance
- Excellent corona resistance.

The generator is self-ventilated, taking in cooling air through the ends and discharging it around the periphery of the stator.

The generator stator is of all welded construction with the laminations held in compression by two end rings acting as belleville springs. Load on the end rings is carried by keys inserted in transverse bars which also locate the laminations and tie together the end frames of the stator.

Excitation System

For improved performance and greater reliability, the design of the excitation system was changed so that excitation is supplied by a regulated, static type exciter in place of the conventional rotating type d-c exciter. This provides the advantages of:

- Elimination of maintenance and brush problems associated with rotating generators
- Faster regulating response.

The rectifier-reactor panel of this exciter is located so as to utilize the engine intake air stream for cooling (Fig. 3). Power for the static exciter is obtained through the auxiliary power transformers located in the control station of the power plant.

The static type excitation, in contrast to the rotating type, provides faster regulating response because it materially reduces the time lag normally associated with the use of rotating exciters. A comparison of the actions of the two types of excitation largely explains this shorter time lag. A rotating exciter and voltage regulator combination senses the alternator voltage output and regulates the exciter field with the resultant exciter output, in turn, controlling the alternator field. The static exciter, on the other hand, senses the alternator voltage output and controls the input to the alternator field directly, thus, eliminating a sizable time factor.

Controls Designed for Automatic, Unattended Operation

The equipment just described illustrates how the design of the three engine-generator components evolved to meet some of the original requirements. The fourth component of the plant is the control and switchgear station containing centralized control equipment for automatic unattended operation and protection of the complete power plant, plus power distribution equipment (Fig. 7).

Switchgear

The design criteria of low cost and minimum size—yet meeting accepted utility standards—prompted the development of a new switchgear design. This switchgear consists of five standardized compartments containing the circuit breakers and coordinated generator control system for the complete generating plant.

The circuit breakers, a 250,000-kva air-magnetic horizontal draw-out type, are located in the center of three compartments. The two end compartments contain the potential transformers, current transformers, protective relays, and meters for the entire power plant. These compartments also contain the three 50-kva, 2400/240/120-volt auxiliary power transformers which draw power from the utility bus to supply generator excitation, immersion heaters, and other accessories.

The superstructure on the switchgear houses the voltage regulating panels of the regulated static exciters. Behind these is located a set of station lightning arrestors and surge capacitors.

The bus sides of the main circuit breakers are connected to a common output bus which terminates in through-the-wall bushings in the end of the unit above the switchgear. These bushings provide external connections from which the user can run overhead or underground lines directly to his distribution system.

A simplified though adequate high voltage protection system has been designed into the generator control equipment to protect it against power system faults. The complete generating plant is protected against external faults by voltage restraint overcurrent relays, and against internal faults by a combined bus and generator differential relay scheme. Appropriate relays also protect against generator overvoltage, overcurrent, field failure, and reverse power.

The metering system also has been simplified so that one set of meters is used for metering either the individual or the total power plant output.

System Control

The heart of the automatic operation feature lies in the system control circuitry and special control equipment developed for this integrated power plant. This is best appreciated by reviewing the events that occur during a typical normal operating sequence of the automatic control system.

Upon receipt of a "start" signal—which may be initiated either by the local push button or by the user's supervisory, carrier current, radio relay, or other signalling system—the master control system is energized, the circuits for engaging the starting motor pinions of all engines are activated, and the first engine to complete this control step will be connected to the battery for cranking. When this engine

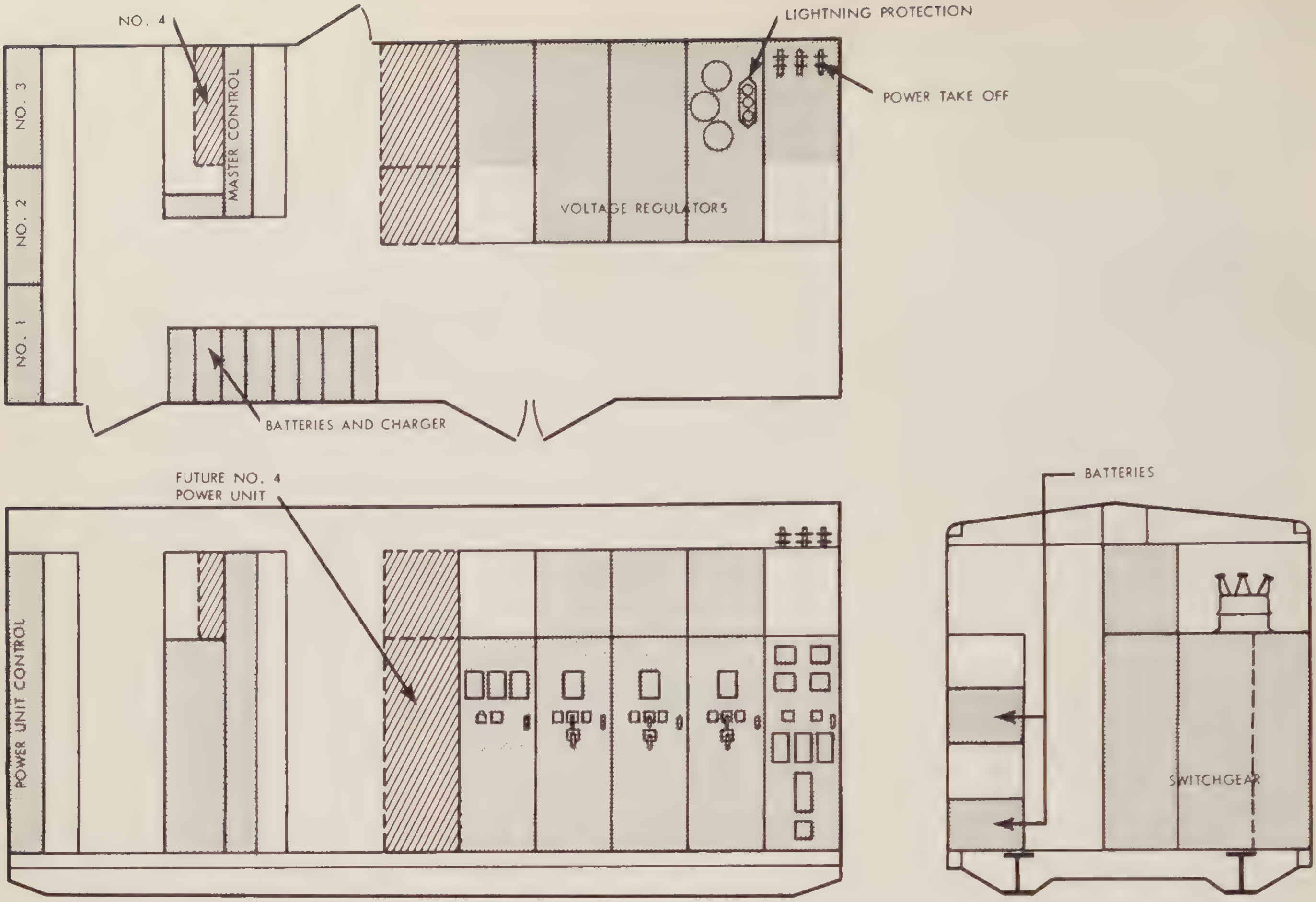


Fig. 7—The arrangement and selection of components in the central control station were made to satisfy the design criteria of automatic, unattended operation, minimum size, and protection against abnormal operation. Five compartments contain switchgear equipment and the auxiliary power transformers which supply power for generator excitation, immersion heaters and other accessories. Separate cabinets contain the equipment required for sequencing operations in the automatic control system of the power plant. A battery compartment houses the battery and battery charging system.

fires, its cranking circuit is opened and the other two engines are immediately cranked in sequence.

As each engine fires, its unit sequencing control system brings it to idle speed for one minute (this step is omitted for an emergency start) then raises it to synchronous speed. At this time excitation is applied to the synchronous generator and when it reaches rated voltage the engine-generator unit is ready to be synchronized to the line.

Here again the master control takes over and the automatic synchronizer is connected to the first unit ready to receive it.

While the voltage regulator matches the generator and bus potentials, the automatic synchronizer supplies control signals to the governor so as to match the frequency and phase of the generator with that of the bus, then it closes the breaker at the moment of synchronization. Each of the other units are then synchronized in rapid succession.

As each unit goes on the line the voltage regulation system controls the generator excitation to supply a controlled amount of reactive power and the unit advances to full load within a few seconds. This completes the starting sequence (Fig. 8). The total time required from start signal to full load for the entire power plant is within 90 seconds.

Upon receipt of a "stop" signal from either the local stop button or remote control, each unit unloads, trips the breaker, allows the engine to cool at idle for three minutes, then shuts down.

At all times the generating plant is adequately protected against abnormal operation. Should such a condition occur, the unit involved would be prevented from starting, or if running, it would be shutdown and locked out until serviced and the control manually reset. The nature of the difficulty would be shown on the station annunciator panel and, if desired, an alarm could be transmitted to a remote control point.

The electrical equipment required for the above sequencing operations is housed in special cabinets separate from the switchgear. One cabinet contains the automatic synchronizer and the other master control devices plus an auxiliary power distribution panel and control system annunciators. The other cabinet contains the unitized automatic sequencing relay panels for the individual engine-generator sets.

The battery compartment houses a 120-volt lead-acid battery used for engine cranking, circuit breaker operation, and control. It is kept fully charged by an automatic battery charger system specifically designed for this type of application.

The housing for the centralized switchgear and control equipment is of heavy duty construction, designed to fulfill the requirements for outdoor type switchgear. Equipment arrangement and housing dimensions are such as to permit

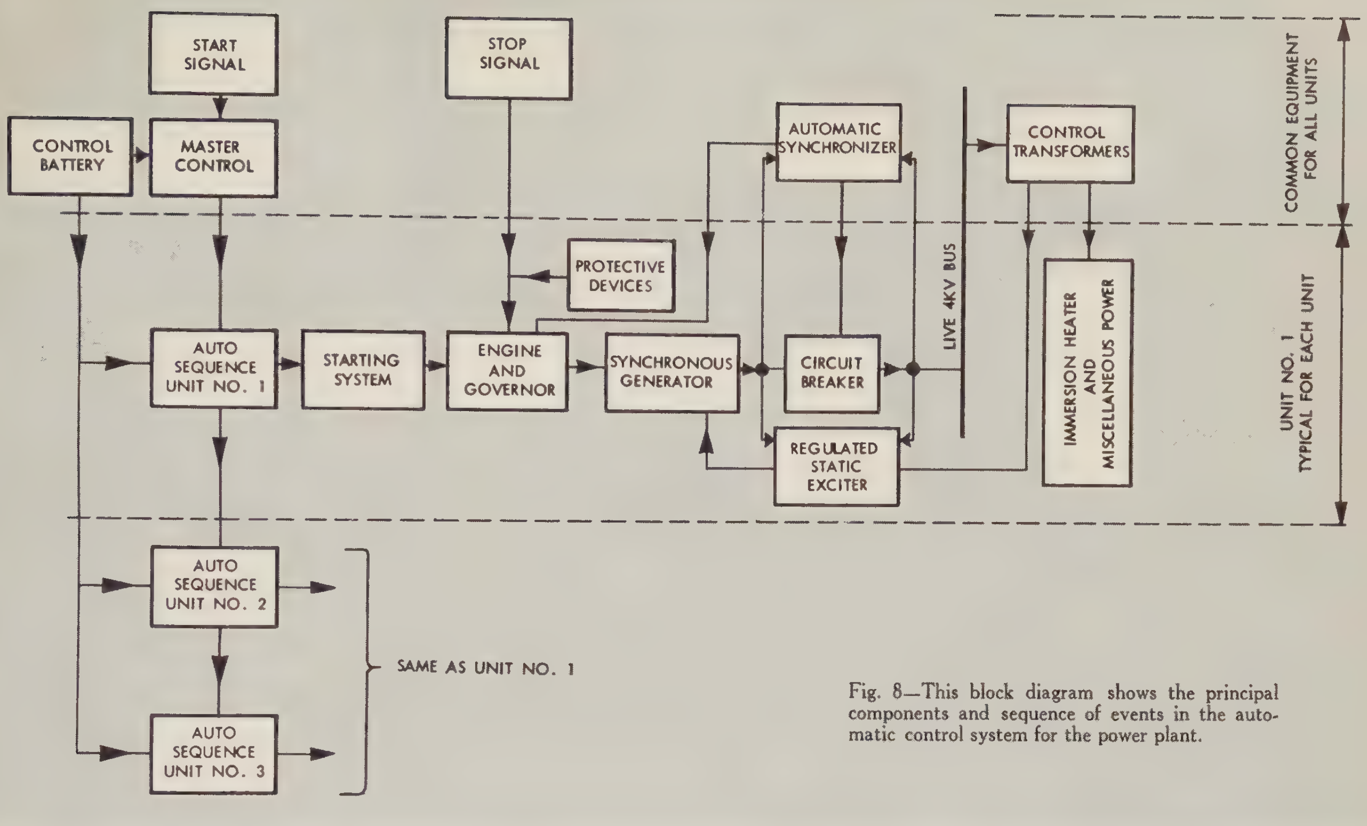


Fig. 8—This block diagram shows the principal components and sequence of events in the automatic control system for the power plant.

circuit breaker withdrawal and maintenance under shelter. All other equipment is readily accessible for servicing. Provision is made for the control of an additional generating unit to make an 8,000-kw plant, if desired.

Enclosures Designed for Sound Deadening, Ease of Installation

The sheet-metal enclosures for the engine-generator and control units of the power plant are designed for quiet operation, easy installation, and servicing of equipment. The engine-generator enclosure is sprayed with a sound-deadening material and, in addition, is equipped with two in. of sound and thermal insulation.

The mounting base of each enclosure is fabricated from rolled steel sections. The base has three lifting and jacking pads on both sides for ease of handling.

The actual installation of the power plant illustrated how the various features of the design contributed to the objective of simplified, low-cost installation. One feature is the separation of the plant into four components, each of which is small enough and light enough to be transported on a railroad flat car, unloaded onto lowboy type highway trailers, and transferred to the site. Another feature is that the engine-generator and control components are completely assembled, tested and ready to run before they are shipped to the user. To place the power plant in operation requires installing a central fuel storage tank, connecting the fuel piping, making electrical connections between the engine-generator units and the control station, and connecting to the user's distribution system.

This peaking plant design requires a minimum of 4,000 sq ft of property which includes space for a 30,000-gal fuel storage tank. Railroad ties and crushed rock, or other suitable supporting means, are used in placing the components of the plant at ground level. The design does not require the expense of concrete foundations, hold-down bolts, or precise leveling.

Summary

The completion of the design work on the new power plant and the actual installation and operation of the plant showed that the objectives had been met. The turbocharged, two-cycle Diesel engine plus the various design improvements in the synchronous generator, accessories, and control circuitry enabled the plant to exceed the power output of 5,000-kw originally called for. The necessary requirements of reliable, unattended operation, low noise level, and minimum maintenance also were met.

Cost studies showed that the 6,000-kw Diesel-powered plant can be installed and operated at a lower cost per kilowatt than the previous Electro-Motive mobile power plants. Furthermore, based on information supplied by utility companies, this lower cost is at a level where it is economical for application to peaking and reserve service.

In power generation for *base load* service, the efficient steam plant, of course, can be operated at a lower cost per kw than the Diesel-powered plant. However, for the occasional demands of *peaking and reserve* service, the steam plant—because of higher initial cost—is expensive. In some systems, it can be so expensive that it becomes economically feasible to consider a special peaking and reserve plant which would provide this service at a lower annual cost per kw. This is the application for which the new 6,000-kw power plant was designed.

Premature Disclosure of Technical Developments

By PAUL J. ETHINGTON
Patent Section
Detroit Office

Checkpoints in research and development for securing patent rights

PUBLIC announcement of technical advances is a daily occurrence and a multitude of technical journals report details of everything from new can openers to gyroscopes. Individuals and corporations alike are understandably eager to make known their achievements and indeed the disclosure of one achievement often stimulates someone to make another. However, this process is not entirely self-sustaining because technical development is costly. In recovering the costs, commercial success is needed and it sometimes depends upon patent rights. While early disclosures of technical developments may be desirable for some purposes, premature disclosures of certain types may foreclose the right to obtain a patent and may result in other commercial disadvantages. Some consideration of how these risks arise and how they can be avoided may be of value to the engineer concerned with new developments.

The Risk of Losing the Right to a Patent

The United States patent laws are exacting in nature and provide that a patent will be refused *if more than one year prior to filing an application for patent the invention was*

(a) described in a printed publication, or
(b) in public use in the United States, or
(c) on sale in the United States.

This statutory requirement is strictly construed and if a patent application is filed even one day beyond the year, the invention is unpatentable. What is a publication and whether it is "printed;" whether a use is "public;" and what is meant by "on sale," are questions that have been litigated in many patent cases. The interpretations of the statute have become quite technical and a few examples may help clarify its meaning.

Even before an invention is actually completed, a "printed publication" describing it more than a year before a patent application is filed will defeat the right to patent. A description of an invention in a book or magazine is clearly a printed publication. Even a typewritten thesis, deposited in a public library more than a year before the patent application, has been held by the courts to be sufficient to bar a patent.

After an invention has been completed by reduction to practice in a new product, "public use" or placing the product "on sale" more than one year before filing a patent application will bar a patent. The public use bar arises from commercial use of an invention in a public place no matter how many persons observe it. Even the use inside a factory where the invention could be observed by persons not committed to secrecy has been ruled a "public use." When a product is on hand and it is offered for sale, it is "on sale" whether or not it is actually sold. But if it has not been built, even though offered for sale, the courts have held that it is not "on sale" within the meaning of the statute. Where the invention is a new process or machine for making a product, the one year period may start running when the product is placed in public use or on sale.

Foreign patent rights may also be of importance and the patent laws of some foreign countries have more stringent requirements regarding public disclosure. In France and Italy, for example, a patent application must be filed *before there is any public use or disclosure sufficient to enable others to practice the invention*. These countries, however, along with the United States and most others, adhere to an International Convention under which a patent application in one country establishes a "priority date." Patent applications filed within one year in the other countries receive the benefit of the priority date. Therefore, where foreign patent rights may be of value, there should be no public disclosure of an invention prior to filing a patent application in the United States.

Other Commercial Disadvantages

Premature disclosure of technical developments can be of great value to others and may even lead to their obtaining patents which stand in the way of a new product. Disclosing the mere idea for a new product may result in the disadvantage of having the competitor reach the market first by an accelerated development program. Even though his development is different, he may make inventions earlier which result in patents of sufficient scope to cover other forms of the product. More detailed disclosures, such as stating the problems encountered, will stimulate the thinking of others and sometimes the recognition of a particular problem is a major step toward solution. Others may find the preferred solution first, particularly if there are any delays in the development, and obtain prior patent rights. Aside from those who act in good faith, there is always some risk that an unscrupulous person will try to patent an invention belonging to someone else. And finally, where a development does not produce any *new* inventions, the final product may require the use of inventions patented earlier by others and premature disclosure may hinder negotiations for the right to use such inventions.

Avoiding the Risks

To avoid the risk of losing patent rights and other disadvantages, close liaison with the patent attorney is necessary. In many companies this is provided by a patent contact engineer who is associated with the engineering programs and is acquainted with patent procedures.

Technical papers should be reviewed by the patent attorney before publication and if inventions are described, the United States patent application should be filed before publication. This will preserve the priority date and permit patent applications to be filed in most foreign countries within the succeeding year. Similarly, the patent attorney should be informed before there is any use of the invention in public so that a patent application can be filed in advance. Even where an invention is conceived but not yet perfected and disclosure to outsiders is necessary, it is good practice to file a patent application on the inventive subject matter before such disclosure. Then if the development continues and details or improvements are worked out to perfect the invention, the patent law permits a type of patent application known as *continuation-in-part* which combines the subject matter of the first patent application with the subsequent developments. In this way, priority of invention is established by the early filed patent application and the patent will set forth the best known embodiment of the invention. This practice is especially useful in development programs which extend over long periods.

When a new product design is completed, the patent applications should be filed before there is any presentation to the public or before production commences to avoid needless jeopardy of patent rights. At this time, the question of adversely held patents also arises and the need for patent infringement investigation should be considered before the product is announced or preparations are made for production. In this way, if there are any valid patents that are infringed by the new product, the necessary rights may be obtained before incurring the expense of tooling and sales promotion of the new product.

Summary

Early disclosure of technical developments is often desirable but if it is premature, it may result in loss of patent rights and may result in earlier inventions and patents by others. Under the patent statutes, a patent will be refused or held invalid when the invention has been in public use, on sale, or described in a printed publication, more than one year prior to the application for patent. Foreign patent rights also may be barred unless the U. S. patent application is filed before such disclosure. To avoid these risks, it is generally desirable to file patent applications and complete the patent investigation before there is any public disclosure of technical developments.

Notes About Inventions and Inventors

The following is a general listing of patents granted in the names of General Motors employes during the period October 1, 1958 to December 31, 1958.

Contributed by

Patent Section

Detroit Office

AC Spark Plug Division
Flint, Michigan

- **Clare B. Rowland,** supervisor, tool room, inventor in patent 2,855,830 for a paper folding machine.

- **Jesse E. Eshbaugh,** (*M.E., University of Cincinnati, 1923*) staff engineer, inventor in patents 2,857,904 for a safety fuel system for engines; 2,860,656 for tank vent structures; and 2,863,140 for systems for indicating liquid level.

- **Alfred Candelise,** (*Ph.D. in electrical-mechanical engineering, University of Naples, 1923*) staff engineer, inventor in patent 2,858,361 for a spark plug center electrode to insulator connector.

- **Martin J. Caserio,** (*Michigan College of Mining and Technology, 1936*) now general manager, Delco Radio Division, and **Henry C. Stuerzl** staff engineer, inventors in patent 2,858,632 for a panel illumination.

- **Jack H. Anderson,** (*B.S.M.E., University of Michigan, 1951*) project engineer, inventor in patent 2,861,820 for a resilient tube to plate connection.

- **James A. Norton,** (*Associate in Science degree, Flint Junior College, 1934; S.B. degree, 1936, and Ph.D. degree in organic chemistry, 1939, University of Chicago*) senior experimental chemist, inventor in patent 2,862,542 for an apparatus and method for corrugating resin impregnated sheet material.

These patent listings are informative only and are not intended to define the coverage which is determined by the claims of each one.

- **Norman J. Amlott,** (*General Motors Institute*) senior project engineer, inventor in patent 2,862,572 for a cleaner silencer assembly.

- **Wilfred A. Bychinsky,** (*B.S.E.E., 1930; M.S.E., 1931; and Ph.D., 1933, University of Michigan*) chief engineer, automotive products, and **Michael Skunda,** supervisor, spark plug production engineering, inventors in patent 2,863,080 for a spark plug and method for making same.

- **William E. Counts,** (*B.S.Cer.E., Georgia Institute of Technology, 1943, and M.S.Cer.E., Pennsylvania State University, 1949*) ceramic engineer; **Karl Schwartzwalder,** (*B.Cer.E., 1930, and M.S., 1931, The Ohio State University*) director of research, Ceramic Laboratory; and **Robert W. Smith,** (*B.S. in physics, University of Chattanooga, 1929, and Ph.D. in physics, University of Michigan, 1933*) supervisor, physics and metallurgy research laboratory, inventors in patents 2,864,773 and 2,864,884 for a semi-conductor composition and a resistor and spark plug embodying same, respectively.

- **John D. McMichael,** (*Michigan State University*) product engineer, inventor in patent 2,865,467 for a cleaner silencer assembly.

- **Earl M. Brohl,** special assignment, Automotive Engineering Department, inventor in patent 2,843,802 for a tell tale circuit.

- **Roscoe M. Wheeler,** automotive engineer, inventor in patent 2,852,737 for an automatic high potential and continuity tester.

- **Edwin F. Katz,** (*B.S.M.E., University of Wisconsin, 1941, and M.S.M.E., The Ohio State University, 1950*) experimental engineer in charge of gyro instruments, Milwaukee plant, inventor in patent 2,850,668 for an electronic harmonic synthesizer.

- **Dimitar Toschkoff,** (*B.S.M.A., Technical College, Sophia, Bulgaria, 1937*) senior project engineer, inventor in patent 2,858,766 for a supercharging pump.

Allison Division
Indianapolis, Indiana

- **Leslie R. Smith,** (*International Correspondence School*) chief draftsman, Turbo-Jet Engineering Department, inventor in patent 2,856,118 for a blading assembly.

- **Arthur W. Gaubatz,** (*B.S., University of Wisconsin, 1920*) senior project engineer, inventor in patents 2,856,246 and 2,865,171 for an antifriction bearing and an engine governor setting mechanism, respectively.

- **Gail E. Hill,** (*B.S.E.E., Purdue University, 1949*) supervisor, electronic and parts test, inventor in patent 2,856,674 for a method of connecting an insulated conductor to a connector terminal element.

- **Charles J. McDowall,** (*B.S.M.E., University of Florida, 1927*) technical assistant to the director of engineering, and **Robert J. Wente,** (*B.S.M.E., Purdue University, 1941*) head, advanced design power turbine controls, inventors in patent 2,856,957 for a pressure operated valve.

- **Richard H. Campbell,** (*International Correspondence School*) senior designer, inventor in patent 2,857,092 for variable compressor vanes.

- **Charles J. McDowall***, inventor in patent 2,857,132 for a turbine wheel.

- **Frederick W. Hoeltje,** (*B.S.M.E., Bradley University, 1940*) senior project engineer; **Wylie L. Johnson III,** (*B.S.Aero.E. Mississippi State College, 1942*) engine project engineer; **John B. Wheatley,** (*A.B. M.E., 1929, and M.E. in aeronautics, 1930, Stanford University*) assistant chief engineer, Advanced Design Engineering Department; and William R. Bain, deceased, inventors in patent 2,857,182 for a shaft seal.

- **Donald G. Zimmerman,** (*B.S.M.E., Purdue University, 1940*) section chief on design projects, inventor in patent 2,859,011 for a turbine bucket and liner.

- **George M. Ferry,** supervisor, drafting, Aircraft Engine Operations, and **Arthur W. Gardiner,** (*A.B. degree, Swarthmore College, 1920*) special assignment, Advanced Design and Development Section, inventors in patent 2,860,482 for a variable nozzle actuating mechanism.

- **Arthur W. Gaubatz***; **Edmund M. Irwin,** (*B.S. in physics, Central Michigan College, 1938*) head, control electronics; **Charles J. McDowall***; and **Robert J. Wente***, inventors in patent 2,860,712 for a control for aircraft power plant.

- **Victor W. Peterson,** (*B.S.M.E., Rose Polytechnic Institute, 1939*) engineer, Advance Design and Development Section, inventor in patent 2,860,713 for a power transmission system.

- **Chester E. Hockert,** (*B.S.M.E., Illinois Institute of Technology, 1937, and M.S. M.E., Cornell University, 1941*) chief engineer, Turbo-Jet Engineering Department, and **Clair A. Short, Jr.,** (*B.S.M.E., 1934, and M.S.M.E., 1936, Georgia Institute of Technology*) section head, Turbo-Jet Engineering Department, inventors in patent 2,861,421 for a gas turbine engine with oil splash shields.

- **Raymond H. Baker,** (*B.S.M.E., The Ohio State University, 1942*) senior project engineer, inventor in patent 2,861,470 for a variable cam.

- **William R. Harding,** (*General Motors Institute, 1946*) supervisor, production control systems, and Arthur W. Davis, no longer with GM, inventors in patent 2,862,355 for a turbine starting fuel system.

*Inventors' names marked with an asterisk have biographical listings noted previously in this issue's Notes About Inventions and Inventors.

- **Esten W. Spears, Jr.,** (*B.S.M.E., University of Kentucky, 1942*) senior project engineer, inventor in patent 2,862,359 for a fuel manifold and flameholder in combustion apparatus for jet engines.

- **Arthur W. Gardiner***, inventor in patent 2,862,654 for variable pitch guide vanes.

- **Otaker P. Prachar,** (*B.S.M.E., 1934, and M.S., 1936, University of Minnesota*) head, Research Group, inventor in patent 2,864,244 for a flexible coupling.

- **Keith A. Bailey,** (*B.S.M.E., Indiana Technical College, 1949*) project engineer; **Howard W. Christenson,** (*B.S., Oregon State College, 1938*) head, Research Department; and **Robert M. Tuck,** (*B.M.E. General Motors Institute, 1947*) development engineer, inventors in patent 2,864,473 for a transmission.

- **Gordon E. Holbrook,** (*B.S., Massachusetts Institute of Technology, 1939*) assistant chief engineer, Engineering Department, inventor in patent 2,865,166 for an after-burner fuel system with pump unloader.

- **William G. Livezey,** (*M.E., International School of Correspondence, 1937*) chief designer, Transmission Engineering Department, inventor in patent 2,865,483 for a lockup clutch means for fluid torque converters and the like.

Aeroproducts Operations
Allison Division
Vandalia, Ohio

- **John D. Moeller,** (*B.S.A.E., and B.N.S., Purdue University, 1949*) senior project engineer; **Clifford B. Wright,** (*A.B., Wittenberg College, 1938*) chief engineer, Aircraft Products; **Thomas Barish,** consultant; and Robert C. Tresder, no longer with GM, inventors in patent 2,855,055 for a propeller mechanism.

- **Richard A. Hirsch,** section head, Electra propellers; **Edward H. McDonald,** (*B.S.M.E., University of Dayton, 1950*) project engineer; and **Harry N. Nelson,** (*Miami University and Denison University*) designer, inventors in patent 2,855,056 for a variable pitch propeller assembly.

- **Dale W. Miller,** (*B.S., Wittenberg College, 1934*) assistant chief engineer; **Walter D. Eby,** (*B.S.M.E., Purdue University, 1942*) senior project engineer; Harold J. Detamore; and Richard E. Moore, no longer with GM, inventors in patent 2,857,007 for a fluid pressure control system for variable pitch propellers.

- **Howard M. Geyer,** (*B.S.I.E., University of Alabama, 1940*) chief research engineer, inventor in patent 2,859,640 for a fluid pressure actuator with unidirectional locking means and manual overdrive.

Buick Motor Division
Flint, Michigan

- **Rudolph J. Gorsky,** (*General Motors Institute, 1935*) staff engineer, inventor in patent 2,855,802 for a coupling for combined hydrodynamic drive device and gear train.

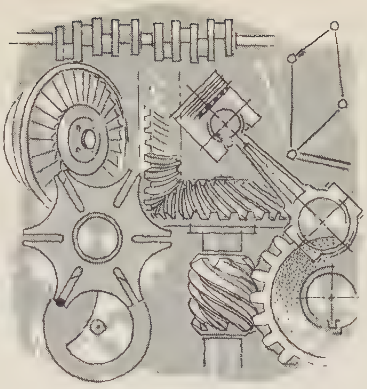
- **Joseph D. Turlay,** (*B.S.M.E., Oregon State College, 1928*) director, power plant activities, inventor in patent 2,856,909 for an engine.

- **Lloyd E. Muller,** (*B.S.M.E., University of Kansas, 1929*) director, experimental engineering, inventor in patents 2,861,479 and 2,865,691 for a driving axle assembly and a journal bearing means, respectively.

- **Harry C. Doane,** now assistant to the vice president in charge of Engineering Staff, inventor in patent 2,863,286 for a control system for power brake system utilizing auxiliary vacuum pump.

- **George R. Bayley,** (*General Motors Institute, 1929*) staff engineer, inventor in patent 2,865,220 for a control mechanism.

- **Oliver K. Kelley,** (*B.S., Chicago Technical College, 1925, and Massachusetts Institute of Technology*) chief engineer, inventor in patent 2,860,747 for hydrodynamic drive devices.



Cadillac Motor Car Division
Detroit, Michigan

- **Harry M. Purdy,** senior project engineer, inventor in patent 2,856,226 for a vehicle frame assembly.

- **Wallace A. Lobdell,** (*B.S.M.E., Tri-State College, 1955*) project engineer, inventor in patent 2,857,893 for an induction system.

- **Henry S. Kawecki,** assistant staff engineer; **Jules A. Olivier,** (*Mechanics Institute, New York*) senior project engineer; and **Gustave J. Chesna,** senior project engineer, Body Engineering Activity, Fisher Body Division, inventors in patent 2,864,647 for a vehicle body-frame construction.

- **Frank M. Prucha,** general master mechanic, inventor in patent 2,865,091 for a ring assembly fixture.

- **Chester J. Glowzinski,** senior project engineer, inventor in patent 2,865,123 for a license plate frame and holder.

Chevrolet Motor Division
Detroit, Michigan

- **Edward N. Cole,** (*General Motors Institute, 1933*) vice president and general manager, inventor in patent 2,857,131 for a flow modulating valve.

- **Adelbert E. Kolbe,** (*University of Michigan*) assistant staff engineer in charge of advanced engine design, and **Earl W. Rohrbacher,** (*B.S.M.E., University of Utah, 1926*) design engineer, inventors in patent 2,862,483 for an engine cooling system.

- **Joseph F. Bertsch,** (*B.S.M.E., University of Cincinnati, 1948*) research engineer, inventor in patent 2,862,726 for a fluid suspension control system.

- **Philip C. Bowser,** (*B.M.E., The Ohio State University*) now director, research and development, Buick Motor Division, and Maurice Olley, retired, inventors in patent 2,864,573 for an engine mounting.

- **Robert S. Plexico,** (*B.S.Ch., Clemson Agricultural and Mechanical College, 1919*) chief truck design engineer, Truck Section, and **Oliver K. Kelley*,** inventors in patent 2,865,227 for a transmission control system.

Delco Products Division
Dayton, Ohio

- **George W. Jackson,** (*B.S.M.E., Purdue University, 1937*) assistant chief engineer in charge of automotive and mechanical products, inventor in patent 2,862,725 for an air suspension system with two stage pressure system.

- **Paul J. Long, Jr.,** (*B.S.M.E., University of Cincinnati, 1941*) section engineer, and **William F. Schmitz,** (*B.I.E., General Motors Institute, 1952*) air-suspension engineer, inventors in patent 2,862,742 for a shock absorber mounting.

Delco Radio Division
Kokomo, Indiana

- **George M. Caskill,** (*B.S. in physics, Franklin and Marshall College, 1951*) senior project engineer, and **Manfred G. Wright,** (*B.S.M.E., Purdue University, 1938*) head, Mechanical Engineering Section, inventors in patent 2,857,519 for a miniature combination tuning means.

- **William R. Kearney,** (*B.S.M.E., Purdue University, 1933*) senior project engineer; **Bertram A. Schwarz,** technical assistant to the general manager; and **Manfred G. Wright*,** inventors in patent 2,858,715 for a solenoid driven tuner with manual drive.

- **James H. Guyton,** (*B.S.E.E., 1934, and M.S.E.E., 1935, Washington University*) chief engineer, radio, inventor in patents

2,861,178 and 2,863,044 for a signal tuned radio control and a sensitivity control for signal seeking tuners, respectively.

- **James H. Guyton***, and Edward G. Roka, deceased, inventors in patent 2,862,175 for a transistor controlled voltage regulator for a generator.

Detroit Diesel Engine Division
Detroit, Michigan

- **John H. Smith**, (*B.S.M.E., University of Michigan, 1949*) application engineer, electrical and governors, and Gerald E. Hook, not with GM, inventors in patent 2,857,006 for an air driven propeller and governor therefor.

- **John Dickson**, (*diploma, Royal Technical College, Glasgow, Scotland*) staff engineer in charge of forward design, inventor in patent 2,862,655 for a pump.

Detroit Transmission Division
Ypsilanti, Michigan

- **Mayo M. Reichardt**, (*B.M.E., 1944, and B.S.E.E., 1957, Lawrence Institute of Technology*) supervisor, machine research and development, inventor in patent 2,860,406 for a roller bearing retainer means.

Diesel Equipment Division
Grand Rapids, Michigan

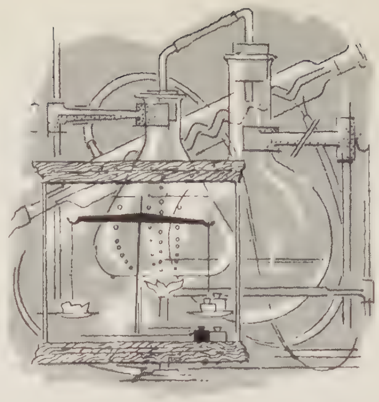
- **Clarence E. Hanson, Jr.**, senior checker, inventor in patent 2,857,894 for a check valve.

- **Elias W. Scheibe**, (*B.S.M.E., University of Michigan, 1940*) senior project engineer, inventor in patent 2,857,895 for a push rod and oil control valve.

- **Ralph A. Underwood** senior electrical engineer, inventor in patent 2,858,696 for a testing apparatus.

Electro-Motive Division
La Grange, Illinois

- **Thomas B. Dilworth**, assistant chief engineer, inventor in patent 2,857,056 for a coupling assembly.



- **Max Ephraim, Jr.**, (*B.S.M.E., Illinois Institute of Technology, 1939*) locomotive section engineer, and **John F. Novacek**, project engineer, inventors in patent 2,859,016 for a heat exchanger.

- **Joseph P. Miller**, (*Purdue University and Cornell University*) now on special assignment at Allison Division; **George E. Rassmussen**, assistant general supervisor, drafting; and **Clarence H. Patrie**, (*B.S. M.E., University of Dayton, 1936*) senior designer, Research Department, inventors in patent 2,862,459 for a railway vehicle truck.

- **Joseph P. Miller***, inventor in patent 2,865,307 for a railway vehicle truck.

- **Charles W. Roth**, (*B.S.E.E., Cornell University, 1929*) electrical controls engineer, inventor in patent 2,866,220 for a windshield wiper transmission assembly.

GM Engineering Staff
Detroit, Michigan

- **Peter P. Kozak**, (*B.S.Ch.E., 1943, and LL.B., 1949, University of Wisconsin*) patent attorney, Patent Section, Detroit office, inventor in patent 2,855,232 for a resiliently mounted ball joint.

- **Maurice A. Thorne**, (*B.A., George Washington University and University of Maryland*) engineer in charge, Vehicle Development Section, inventor in patents 2,857,975 and 2,865,436 for a vehicle half axle drive assembly and a seat, respectively.

- **Maurice A. Thorne***, and **Lothrop M. Forbush**, (*B.S., Harvard University, 1939, and Massachusetts Institute of Technology*) assistant engineer in charge, Passenger Car Development Group, inventors in patent 2,859,839 for a combination hydraulic and mechanical brake.

- **Gilbert K. Hause**, engineer in charge, Transmission Development Group, inventor in patent 2,860,731 for a positive parking brake.

- **John W. Pyuro**, body engineer, and Gerhard C. R. Kuiper, retired, inventors in patent 2,860,913 for a folding top with inwardly collapsing side rails.

- **Charles A. Chayne**, (*B.S.M.E., Massachusetts Institute of Technology, and Harvard University, 1919*) vice president in charge, and **Von D. Polhemus**, (*B.S.M.E., University of Cincinnati, 1933*) engineer in charge, Structure and Suspension Development Group, inventors in patent 2,865,651 for a combined wheel hop damper and air spring suspension.

Euclid Division
Cleveland, Ohio

- **Edward R. Fryer**, (*General Motors Institute and B.S.M.E., Massachusetts Institute of Technology, 1945*) senior project engineer, and William J. Adams, retired, inventors in patent 2,857,009 for a hydraulic power unit for tractors equipped with power steering and power operated implements.

- **Harold C. Schindler**, chief product engineer, scraper engineering, inventor in patent 2,864,479 for a transmission-hydraulic clutch bleed-off valve.

Fabricast Division
Bedford, Indiana

- **Harold L. Benham**, (*B.S. in physics, Indiana University, 1951*) development engineer, inventor in patent 2,861,308 for a refractory mold having high permeability, composition for making, and method of making same.

Fisher Body Division
Detroit, Michigan

- **Engelhart A. Meyer**, senior project engineer, inventor in patent 2,856,217 for a rod end retaining clip.

- **Joseph L. Lelli,** (*B.M.E., General Motors Institute, 1948*) assistant engineer in charge, Experimental and Development Department, inventor in patent 2,856,987 for a spring construction.

- **Louis P. Garvey,** (*B.M.E., University of Detroit, 1940*) assistant engineer in charge, Product Engineering Activity, and **Claud S. Semar,** (*Detroit City College, University of Michigan, and Wayne State University*) senior project engineer, inventors in patent 2,858,878 for a seat adjusting mechanism.

- **Emil J. Wiese,** engineer, Plant Contact and Quality Control Department, inventor in patent 2,860,905 for a door lock striker and bumper.

- **Bart Cotter,** chief engineer, Body Engineering Activity, inventor in patent 2,860,911 for an automobile body pillar and door construction.

- **Wilfred J. Larabell,** engineer in charge, Trim Engineering Department, inventor in patent 2,862,227 for a carpet retaining staple.

- **James D. Leslie,** (*B.M.E., University of Detroit, 1939*) engineer in charge, Mechanical Department, and **Henry J. Wubbe,** layout draftsman, inventors in patent 2,862,703 for a window regulator.

- **Alfons A. Limberg,** (*Automotive Engineering School, Berlin, Germany*) now chief engineer, body and truck exteriors, GM Styling Staff, inventor in patent 2,864,432 for an inertia latch for vehicle seats.

- **Stanley D. Cockburn,** (*Lawrence Institute of Technology*) senior designer, and **Charles J. Griswold, Jr.,** (*B.S. in engineering mechanics, Purdue University, 1953*) assistant engineer in charge, Body Engineering, Design and Drafting Department, inventors in patent 2,864,639 for a remote handle blockout for automobile door latch.

- **James D. Leslie*,** inventor in patent 2,864,641 for an inertia safety device for a door latch.

- **Ralph M. Stallard,** (*B.S.E.E., Michigan College of Mining and Technology, 1949*) senior project engineer, inventor in patent 2,865,400 for a solenoid operated air valve.

Frigidaire Division
Dayton, Ohio

- **John Weibel, Jr.,** (*B.S.M.E., Louisiana State University, 1948, and M.S.M.E., Purdue University, 1950*) senior project engineer, inventor in patent 2,855,139 for a refrigerating apparatus.

- **Verlos G. Sharp,** (*B.S.M.E., Purdue University, 1948*) section engineer, inventor in patent 2,855,262 for a refrigerator storage tray.

- **James W. Jacobs,** (*B.S.M.E., University of Dayton, 1954*) manager, Research and Future Product Engineering, inventor in patents 2,855,761 and 2,866,528 for an engine driven refrigerating apparatus and a clutch for refrigerating apparatus, respectively.

- **Rolf M. Smith,** (*M.E., University of Minnesota, 1929*) now senior project engineer, Allison Division, inventor in patent 2,856,119 for a refrigerating apparatus.

- **Daniel J. Barbulesco,** (*B.S.M.E., Stanford University, 1949*) project engineer, inventor in patent 2,856,759 for a refrigerating evaporative apparatus.

- **John M. Murphy,** (*B.S.E.E., Purdue University, 1930*) supervisor, Major Product Line, and **Leonard J. Mann,** (*M.E., University of Cincinnati, 1940*) senior project engineer, inventors in patents 2,859,595 and 2,863,300 for a two temperature refrigerator with forced air circulation and a refrigerating apparatus, respectively.

- **Kenneth O. Sisson,** (*B.S.M.E., South Dakota State College, 1936*) senior project engineer, inventor in patent 2,859,877 for a suspension system for spinner type washing machine.

- **George B. Long,** (*B.S.E.E., Purdue University, 1937*) supervisor, Major Product Line, inventor in patent 2,860,026 for a domestic appliance.

- **Richard S. Gaugler,** (*B.S.Ch.E., Purdue University, 1922*) supervisor, Major Product Line, inventor in patent 2,863,179 for a refrigerating apparatus.

- **Clifford H. Wurtz,** (*B.S., University of Illinois, 1929*) supervisor, Major Product Line, inventor in patent 2,863,303 for a refrigerating apparatus.

- **Byron L. Brucken,** (*B.S., University of Dayton, 1956*) senior project engineer, inventor in patent 2,863,311 for a gyration and rotation mechanism for domestic appliance.

- **John Weibel, Jr.*,** and **Irving M. Pelsor,** no longer with GM, inventors in patent 2,864,550 for a refrigerating apparatus.

- **John H. Heidorn,** (*General Motors Institute, 1947*) project engineer, and Richard J. Becht, no longer with GM, inventors in patent 2,864,551 for a refrigerating apparatus.

- **Keith K. Kesling,** (*University of Dayton and Dayton Art Institute*) project and design engineer, inventor in patent 2,866,675 for a refrigerator.

Harrison Radiator Division
Lockport, New York

- **G. Walter Gerstung,** (*B.S.M.E., University of Kentucky, 1927*) engineer in charge, Product Study Section, inventor in patents 2,858,112 and 2,860,722 for a heat exchanger and a silencer, respectively.

Inland Manufacturing Division
Dayton, Ohio

- **Edward P. Harris,** (*M.E., Cornell University, 1931*) project engineer; **James R. Wall,** (*B.Ch.E., University of Dayton, 1937, and M.Ch.E., Cornell University, 1939*) supervisor, advanced development laboratory; and **Frederick W. Sampson,** (*M.E., Cornell University, 1924*) section engineer on special assignment at Moraine Products Division, inventors in patent 2,858,095 for a valving device.

- **Max P. Baker,** (*A.B., Miami University, 1922*) project engineer, inventor in patent 2,862,741 for an oscillatory joint.

GMC Truck and Coach Division

Pontiac, Michigan

- **Hans O. Schjolin,** (*B.S., Carlstad College, Sweden, 1920, and Polytechnical Institute, Mittweida, Germany, 1923*) advance design engineer, inventor in patents 2,856,049 and 2,861,482 for a clutch plate and a transmission, respectively.

- **Helmuth Guentsche,** (*engineering degree, Technical University of Berlin, Charlottenberg, Germany, 1923*) drafting supervisor; **Millis V. Parshall,** (*B.S.M.E., University of Michigan, 1918*) project engineer; and **Hans O. Schjolin***, inventors in patent 2,858,142 for a torsion bar independent wheel suspension.

- **Millis V. Parshall***, inventor in patent 2,862,362 for a fluid coupling construction.

Guide Lamp Division

Anderson, Indiana

- **Charles W. Miller,** (*Purdue University*) project engineer, inventor in patent 2,861,193 for a light sensitive control circuit.

- **Lucien W. Pryor,** (*Purdue Technical Institute*) designer, inventor in patent 2,862,419 for a rear view mirror.

- **David P. Clayton,** designer, and **Lyle N. Williams,** (*A.B.Ch., Indiana University*) senior project engineer, inventors in patent 2,866,082 for a wire spring lens retainer.

- **George W. Onksen,** (*B.I.E., General Motors Institute, 1956, and Purdue University*) engineering head, Research and Development Department, inventor in patent 2,866,131 for a light controlled oscillator in automatic headlamp dimmer system.

Moraine Products Division

Dayton, Ohio

- **Roland P. Koehring,** (*Earlham College*) chief metallurgist, Engineering Department, inventor in patents 2,855,296 and 2,866,886 for a method of sintering nickel powder onto stainless steel and a method of manufacture, respectively.

- **Calvin J. Werner,** (*E.E., University of Cincinnati, 1930*) general manager, inventor in patent 2,862,623 for a filter.

- **Frederick W. Sampson***, inventor in patent 2,864,168 for a sight system for firearms.

Oldsmobile Division

Lansing, Michigan

- **Russell E. Hansen,** assistant general manufacturing manager, inventor in patent 2,856,675 for a method of making turbomachine blading.

- **Henning W. Rundquist,** (*B.S., Michigan State University, 1929*) senior project engineer, inventor in patent 2,857,926 for a manifold heat control valve.

- **James H. Lewis,** (*B.S., Iowa State College, 1940*) chassis engineer, inventor in patent 2,861,418 for an exhaust system.

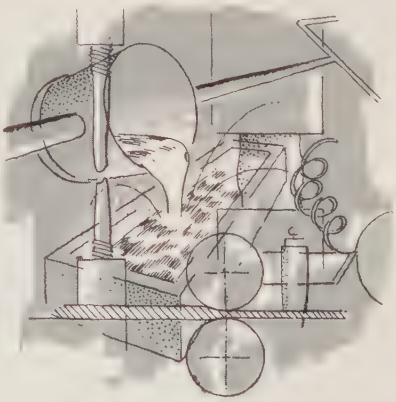
- **Blair N. Nixon,** senior project engineer, inventor in patent 2,865,653 for a filler access mechanism.

GM Overseas Operations Division

New York, New York

- **Harold E. Coverley,** new product engineer, AC-Delco Division, GM Limited, London, England, inventor in patent 2,857,016 for air cleaners.

- **Heinrich Benz,** (*Rheinische Ingenieurschule Bingen, 1922*) and **Wilhelm Riehl,** (*Staatliche Ingenieurscule Darmstadt, 1931*) senior designers, Adam Opel A.G., Russelsheim/Main, Germany, inventors in patent 2,859,071 for a rotary shaft seal.



- **Milton A. Trisler,** (*Otterbein College, 1926*) accessories engineer, Detroit Engineering Staff, inventor in patent 2,862,490 for an engine.

- **James R. Gorst,** (*Peter Symonds College, Winchester, England*) laboratory assistant, and **Stanley W. Kemp,** (*Acland Central Technical College and Luton Technical College, England*) experimental engineer, AC-Delco Division, GM Limited, London, England, inventors in patent 2,865,531 for a closure cap for the cooling systems of internal combustion engines.

Pontiac Motor Division

Pontiac, Michigan

- **Clayton B. Leach,** (*A.B. in mathematics and chemistry, Park College, 1934, and General Motors Institute*) chassis engineer, inventor in patents 2,858,587 for a cylinder head coring for overhead valve engines; 2,864,351 for a valve actuation mechanism; and 2,865,361 for an engine lubricating system.

- **Mark H. Frank,** (*B.S.M.E., Michigan State University, 1927*) motor engineer, inventor in patents 2,865,354 and 2,865,360 for an intake valve vent means and a combustion chamber and method of forming combustion cavities, respectively.

GM Research Laboratories

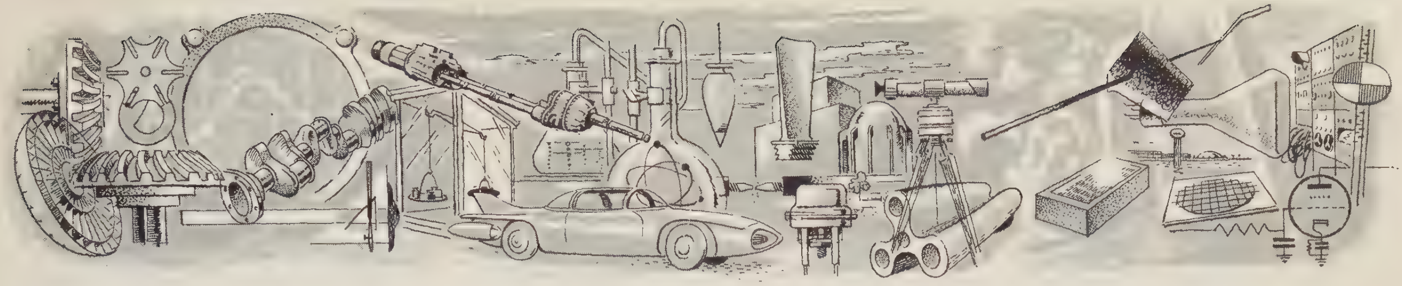
Detroit, Michigan

- **Robert F. Thomson,** (*B.S.M.E., 1937; M.S.M.E., 1940; and Ph.D. 1941, University of Michigan*) head, Metallurgical Engineering Department, inventor in patent 2,855,659 for a sintered powdered metal piston ring.

- **Charles W. Vigor,** (*B.S.Met.E., University of Michigan, 1950*) senior metallurgical engineer, inventor in patent 2,858,600 for a surface hardening of titanium.

- **Donald F. Hays,** (*B.S.M.E. and M.S.M.E., Oregon State College, 1951*) research engineer, inventor in patent 2,860,776 for a classifying apparatus.

- **Donald R. Whitney,** (*B.S.M.E., University of Michigan, 1942*) supervisor, mis-



sile system bearings, inventor in patent 2,860,882 for a work chuck.

- **Alfred L. Boegehold,** (*M.E., Cornell University, 1915*) consultant; **Fred J. Webbere,** (*B.S., University of Wisconsin, 1941*) supervisor, Metallurgical Engineering Department; and **Dean K. Hanink,** (*B.S.Met.E., University of Michigan, 1942*) now chief metallurgist, Allison Division, inventors in patent 2,860,968 for a wrought high temperature alloy.

- **Frederick W. Chapman,** (*B.S.E.E., University of Michigan, 1938*) senior engineer, and Edward J. Martin, retired, inventors in patent 2,861,234 for a servo controlled follower system.

- **Charles F. Froberger,** (*B.S.Ch., Notre Dame University, 1944, and M.S.Ch., Michigan State University, 1950*) senior research chemist, inventor in patent 2,861,307 for shell molds.

- **Fred G. Rounds,** (*B.S.Ch.E., Washington State College, 1949*) senior research engineer, and **Ralph E. Schwind,** (*B.S. M.E., Purdue University, 1950, and S.M. M.E., Massachusetts Institute of Technology, 1951*) now product engineer, Fabricast Division, inventors in patent 2,862,481 for an addition of flame moderators to combustion chambers.

Rochester Products Division
Rochester, New York

- **Donald G. Dening,** (*A.A.S. in M.E., Rochester Institute of Technology, 1948*) project engineer, inventor in patent 2,858,409 for a circuit breaker for cigar lighter.

- **Elmer Olson,** (*Lewis Institute*) inventor in patents 2,859,700 and 2,862,487 for a windshield washer pump and a carburetor throttle mechanism, respectively.

- **Lawrence C. Dermond,** (*Purdue University and Tri-State College*) staff engineer, inventor in patents 2,860,616 and 2,864,596 for an atmospheric nozzle control and a carburetor, respectively.

- **Joseph M. McDonnel,** (*Newark College of Engineering*) senior engineer, inventor in patent 2,862,450 for a pump.

Saginaw Steering Gear Division
Saginaw, Michigan

- **W. Blair Thompson,** (*B.M.E., General Motors Institute, 1950*) assistant chief engineer; C. W. Lincoln, retired; and Wayne H. Watling, no longer with GM, inventors in patent 2,858,805 for a means for reducing relief valve squeal in a hydraulic power steering gear.

GM Styling Staff
Detroit, Michigan

- **Donald D. Hoagg,** (*Pratt Institute, 1949*) chief designer, Design Development Studio, and Arthur Ross, no longer with GM, inventors in patent 2,856,020 for an automobile exhaust means.

- **Michael J. Galla, Sr.,** supervisor, engineering, Advanced Design Studios, inventor in patent 2,856,227 for an automobile body mounting.

- **Delbert C. Probst,** (*Milliken University, 1922*) senior design engineer, Exterior Engineering Department, and Joseph A. Johnson, no longer with GM, inventors in patent 2,856,983 for an easy entrance seat.

- **John Himka,** (*diploma in Aero.E., Academy of Aeronautics, 1941*) general supervisor, Body Development Studio, and **Edwin R. Howell, Jr.,** supervisor, Body Development Studio, inventors in patent 2,857,198 for a door actuated roof closure for vehicle side door opening.

- **Robert F. McLean,** (*B.S.M.E., 1943, and professional degree in industrial design, 1948, California Institute of Technology*) executive in charge of styling, product analysis, and planning, and John V. Huff, no longer with GM, inventors in patent 2,860,720 for an adjustable toeboard for an automobile.

- **Kenneth R. Betts,** (*Tri-State College, 1925*) project engineer, Truck Studio, and **Matthew R. Whitman,** senior design engineer, Interior Engineering Department, inventors in patent 2,864,299 for a vehicle ventilator.

Ternstedt Division
Detroit, Michigan

- **Samuel F. Loria,** (*B.S.M.E., Detroit Institute of Technology, 1939*) chief draftsman, inventor in patent 2,857,617 for a door check and hold-open.

- **George W. Sierant,** (*B.S.M.E., Lawrence Institute of Technology, 1947*) design group leader, inventor in patent 2,860,521 for a mechanical movement device.

- **Robert M. Hebert,** (*B.S.M.E., Wayne State University, 1954*) drafting group supervisor, inventor in patent 2,861,832 for a rotary bolt door latch.

- **J. George Hertlein,** (*Rutgers University*) senior product engineer, tools, Trenton, New Jersey, plant, and **Bewley D. Priestman,** (*B.A. in engineering science, 1938, and M.A.M.E., 1942, University of Cambridge, England*) engineering group supervisor, inventors in patent 2,862,753 for an outside door handle assembly.

Technical Presentations by GM Engineers and Scientists

The technical presentation is another way in which information about current engineering and scientific developments in General Motors can be made available to the public. A listing of speaking appearances by General Motors engineers and scientists, such as that given below, usually includes the presentation of papers before professional societies, lecturing to college engineering classes or student societies, and speaking to civic or governmental organizations. Educators who wish assistance in obtaining the services of GM engineers and scientists to speak to student groups may write to the Educational Relations Section, Public Relations Staff, General Motors Technical Center, P. O. Box 177, North End Station, Detroit 2, Michigan.

The following GM personnel made recent technical presentations.

Automotive Engineering

Frank O. Riley, director, product engineering and development, Ternstedt Division, before the American Society of Body Engineers, Detroit, October 23; title: Engineering of Ornamental and Mechanical Automotive Body Hardware.

E. F. DeTiere, Jr., supervisor, fuel injection engineering, Rochester Products Division, before the Rochester, New York, Institute of Technology student chapter of the American Society of Tool Engineers, November 11; title: Fuel Injection.

George W. Niepoth, supervisor, engineering tests, GM Engineering Staff, before the Society of Automotive Engineers, Detroit section, junior activity, November 17; title: Performance and Economy Gains with Light Weight Materials.

Louis C. Lundstrom, director, GM Proving Grounds, before the American Association of State Highway Officials, San Francisco, November 30; title: Roadside Hazards and Highway Design for Safety; and before the fifth annual Bituminous Conference, University of Minnesota, Minneapolis, November 19; title: Safety Aspects of Vehicle-Road Relationships.

Donald H. McPherson, staff engineer, Chevrolet Motor Division, before personnel of Continental Motors Corporation, Detroit, November 20; title: Engineering the "W" Engine—Chevrolet's 348 Cubic Inch V-8.

Bart Cotter, chief engineer, Product Engineering Activity, Fisher Body Division, before the A.S.B.E., Detroit, December 4; title: Body Engineering—Capturing the Stylist's Dream.

Nelson E. Farley, staff engineer, Chevrolet Motor Division, before the Milwaukee section of the S.A.E., December 5; title: Chevrolet's New Engineering Laboratory.

L. C. Rowe, senior research chemist, GM Research Laboratories, before the annual meeting of the Chemical Specialties Manufacturers Association, New York City, December 9; title: Can Automotive Engine Coolants Keep Pace With Future Demands?

T. M. Fisher, head, Technical Data Department, GM Proving Grounds, before the Northwestern Pennsylvania Society of Engineers, Oil City, December 11; title: Proving Ground Testing, Facilities, and Instrumentation.

Clare D. Harrington, administrative engineer, Oldsmobile Division, before the Lansing, Michigan, Exchange Club, December 29; title: Styling of the New Car.

Paul C. Skeels, head, Experimental Engineering Department, GM Proving Grounds, before the Chicago section of the Instrument Society of America, January 5; title: Automotive Proving Ground Instrumentation.

Donald Stoltman, senior engineer, Rochester Products Division, before the Syracuse, New York, General Electric Engineers Association, January 8; title: Automotive Carburetion.

GM Proving Grounds personnel who made presentations before the 38th annual meeting of the Highway Research Board, Washington, D. C., January 9, included **Louis C. Lundstrom,** director, and **Paul C. Skeels,** head, Experimental Engineering Department, title: Full Scale Appraisals of Guardrail Installations by Car Impact Tests; and **Kenneth A. Stonex,** assistant director, title: Summary—Committee Report on Relationships of Vehicle Dynamics to Skidding.

William H. Jackson, supervising engineer, Harrison Radiator Division, before the American Society of Refrigeration Engineers, San Antonio, Texas, January 19; title: 1959 General Motors Air Conditioning.

John Dickson, staff engineer, Detroit Diesel Engine Division, before S.A.E. meetings in Denver, Colorado, and San Antonio, Texas, January 21 and 28, respectively, and before the California Trucking Association Meeting, San Diego, January 23; title: Explanation of the New Line of Diesel Engines.

Max M. Roensch, assistant chief engineer, Chevrolet Motor Division, before the Rochester, New York, section of the S.A.E., February 2; title: Chevrolet's New Engineering Laboratory.

George A. Brown, field contact engineer, AC Spark Plug Division, before the Industrial Arts Association of Pennsylvania, Hershey, November 25; title: Proper Selection, Installation, and Maintenance of AC Products.

S.A.E. Annual Meeting

The following GM personnel made presentations at the S.A.E. 1959 annual meeting, Detroit, January 12-16. From the GM Research Laboratories: **J. B. Bidwell,** head, Engineering Mechanics Department, title: Vehicles and Drivers—1980; **L. L. Withrow,** head, Fuels and Lubricants Department, title: Better Technical Papers for the S.A.E.; **W. A. Turunen,** head, and **J. S. Collman,** assistant head, Engineering Development Department, title: The GT-305 Regenerative Engine; **G. H. Robinson,** supervisor, **R. F. Thomson**, head, and **F. J. Webbere**, supervisor, Metallurgical Engineering Department, title: The Use of Bench Wear Tests in Materials Development; **J. B. Bidwell**, head, **R. M. VanHouse**, supervisor, and **R. S. Cataldo**, senior research engineer, Engineering Mechanics Department, title: Firebird III—Chassis and Control Details; **G. J. Nebel**, senior research engineer, and **R. W. Bishop**, research engineer, Fuels and Lubricants Department, title: Catalytic Oxidation of Automobile Exhaust Gases. From Chevrolet Motor Division: **N. H. McCuen**, staff engineer, title: What's New in Brake Linings. From the GM Engineering Staff: **James Gumbleton**, project engineer, title: Engine Voltage Requirements Using Spark Plugs Pre-Ionized with Radioactive Gold. From GMC Truck and Coach Division: **C. V. Crockett**, chief engineer, and **Donald J. LaBelle**, truck engineer, title: A New Concept of Lightweight Highway Tractor Design. From the GM Styling Staff: **R. F. McLean**, executive in charge, research, product planning, and analysis, title: Firebird III—General Arrangement and Body Design. From Detroit Diesel Engine Division: **K. L. Hulsing**, staff engineer, and **C. E. Ervin**, assistant staff engineer, title: GM Diesel's Additional Engines—New "V's" and In-Lines. From Saginaw Steering Gear Division: **Philip B. Zeigler**, chief engineer, title: The New Saginaw Rotary Valve Gear. From Buick Motor Division: **Oliver K. Kelley**, chief engineer, title: Design of Successful Planetary Gear Trains. From Harrison Radiator Division: **J. W. Godfrey** and **C. V. Hawk**, assistant chief engineers, title: Indoor Climatic Testing of Automotive Engine Cooling and Air Conditioning Systems.

Foundry

Charles E. Fausel, manufacturing superintendent, Central Foundry Division, before the Malleable Founders Society, Cleveland and Chicago, November 20 and 21, respectively; title: Slag Control in Castings; and before students of the University of Illinois, Chicago, December 4; title: Opportunities in the Foundry Industry.

C. Schaefer, supervisor, ceramic development and control, AC Spark Plug Division, before the southwestern Ohio section of the American Ceramic Society, Cincinnati, January 16; title: Compression, Injection, and Isostatic Molding.

Karl Schwartzwalder, director, Research Department, AC Spark Plug Division, before the Chemical Institute of Canada, Arvida, Quebec, January 27; title: Alumina Ceramics; and before the Canadian Ceramic Society, Toronto, February 10; title: Compression, Injection, and Isostatic Molding.

Elmer E. Braun, works manager, Central Foundry Division, before the American Foundrymen's Society, Indianapolis, February 2; title: A New Approach to Marketing Castings.

Guided Missiles

The following engineering personnel of AC Spark Plug Division made recent presentations on guided missiles and inertial guidance systems.

Richard Bartek, project engineer, before the northeastern Michigan section of the American Institute of Electrical Engineers, Saginaw, January 12; title: Control Systems for Space Flight.

Leonard E. A. Batz, scientific gyroscope advisor, before the Michigan Townships' Association Convention, Lansing, January 14; title: Rockets, Missiles, and You.

Tom O'Connell, head, Development Inertial Guidance Department, before the Air Force Reserve Center, Milwaukee, January 12; title: Missile Guidance.

L. W. Tobin, Jr., manager, AC Milwaukee plant, before the Kenosha, Wisconsin, College Club, January 20; title: The Mrs. Behind the Missile.

Don Carpentier, senior project engineer, before the Mt. Carmel Men's Club, Milwaukee, January 20; title: The Missile and Its Challenge to Industry.

R. R. Kordes, engineer, before the Waukesha, Wisconsin, Radio Amateurs Society, January 28; title: Principles of Inertial Guidance.

Hans Hauser, office head, Mace project, before the Wauwautosa, Wisconsin, Kiwanis Club, February 3; title: Guided Missiles.

Herman Brandt, engineering materials supervisor, AC Milwaukee plant, before Ivanhoe Temple, February 5; title: Missiles:

J. F. Shea, director, Advanced Systems Engineering and Research Department, before Massachusetts Institute of Technology alumni, Milwaukee, February 12; title: Evolution of Ballistic Missiles and Space Programs in the U. S.

Manufacturing

Leonard B. Wocholski, associate chairman, Science Department, General Motors Institute, before the A.S.M.E. and the American Society of Safety Engineers, Chicago, October 22; title: Safe Operation of Industrial Furnaces.

Gene F. Wiley, process engineer, Delco Radio Division, before the American Welding Society, Indianapolis, December 12; title: An Analysis of Welded Contacts for Light Duty Switch Applications.

R. D. McLandress, director, Work Standards and Methods Engineering Section, GM Process Development Staff, before the Detroit chapter of the Society for Advancement of Management, December 16; title: Utilizing Methods Engineering in Cost Reduction.

Edward R. Clark, supervisor, Quality Control Department, Detroit Transmission Division, before the Kankakee-Joliet, Illinois, section of the American Society for Quality Control, February 2; title: Corrective Action.

John Panek, project engineer, GM Process Development Staff, before the St. Louis, Missouri, section of the A.S.T.E., February 3; title: What Do We Mean by Fire Resistance?

Karl Sarafian, senior production engineer, Fisher Body Division, before the Syracuse, New York, section of the American Welding Society, February 11; title: Electronics in Resistance Welder Controls.

Mathematics and Computers

T. J. Theodoroff, research physicist, and **J. T. Olsztyn**, senior mathematics programmer, GM Research Laboratories, before the Eastern Joint Computer Conference, Philadelphia, December 5; title: DYANA: Dynamics Analyzer, Programmer.

Robert E. Henderson, head, Applied Physics Group, Allison Division, before the National Science Teachers Association, Indianapolis, December 27; title: Computers; and before students of Purdue University, Lafayette, February 13; title: Engineering Problems for Computers.

L. G. Johnson, senior research mathematician, GM Research Laboratories, before the 1958 annual meeting of the Joint Allied Social Sciences Association, Chicago, December 29; title: A Computer Program for Assessing the Reliability of an Assembly Consisting of Components with Known Weibull Survivorship Functions.

F. E. Jablonski, senior nuclear physicist, GM Research Laboratories, before the national meeting of the American Nuclear Society, Detroit, December 9; title: Unlimited Dynamic Range Analysis of Fast Reactor Transients With an Analog Computer.

K. L. Nielsen, chief, applied mathematics, Allison Division, before the 5th Joint Military-Industry Symposium on Guided Missile Reliability, Chicago, December 10; title: The Contribution of Mathematics to a Reliability Program.

Metallurgy

C. W. Vigor, senior metallurgical engineer, GM Research Laboratories, before the 16th annual electric-furnace steel conference of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Detroit, December 5; title: Survey of Exhaust Valve Materials, Past and Present.

Robert J. Kick, senior project engineer, Moraine Products Division, before the Dayton section of the S.A.E., January 20; title: The New Look in Sintered Steel.

W. B. Larson, metallurgical engineer; **Frank J. Webbere**, supervisor; and **Robert F. Thomson**, head, Metallurgical Engineering Department, GM Research Laboratories, and **Carl F. Joseph**, technical director, Central Foundry Division, before the Wisconsin chapter of the A.F.S., February 12; title: CentraSteel—A High Modulus Cast Graphite Steel.

Miscellaneous

William C. Cole, section manager, AC Spark Plug Division, before employes of the Airwork Corporation, Cleveland, November 11; title: Aircraft Spark Plugs.

Marshall D. McCuen, section chief, Allison Division, before the Central Association of Mathematics and Science Teachers, Indianapolis, November 29; title: Today's Space Age Needs Chemistry's Cornucopia.

Ralph O. Helgeby, staff engineer, AC Spark Plug Division, before the Lions Club of Flushing, Michigan, December 2; title: Impressions from Europe—Summer, 1958.

M. C. Hardin, fluid dynamics engineer, Allison Division, before the Manual High School Science Club, Indianapolis, December 5; title: What Is a Fuel?

E. B. Spangler, research engineer, GM Research Laboratories, before the U.S. Navy Bureau of Ships, Washington, D.C., December 9; title: 15,000 HP Friction Drive Speed Reducer.

H. B. Simpson, senior technical writer, GM Research Laboratories, before the tenth annual mid-American electronics convention, Kansas City, Missouri, December 10; title: The Characteristics of Technical Writing.

L. N. Williams, senior project engineer, and **George W. Onksen**, engineering head, research and development, Guide Lamp Division, before faculty members of Purdue University, January 2; title: Engineering Development Activities.

Robert K. Burns, education director, Delco Products Division, before members of the Techniclub, University of Dayton, Ohio, January 12; title: Future of the Engineering Technician.

George J. Clingman maintenance and operations engineer, Allison Division, before the Indiana section of the American Chemical Society, Indianapolis, November 25; title: The Lockheed Electra and What It Means to Indianapolis; before Broad Ripple ME Church, January 12; before the Catholic Mens' Club, January 20; and before the Naval Avionics Facility Masonic Pin Club, January 26; all in Indianapolis; title: The Lockheed Electra and Allison 501 Engines.

J. M. Biedenbach, section head, General Motors Institute, before students of Freeman School, January 20, and students of Pierce School, January 27, Flint; title: Physical Science Demonstrations.

Tibor F. Nagey, director of research, Allison Division, before the Indiana section of the S.A.E., Indianapolis, December 11; title: Nuclear Rocket Propulsion—A Survey of Proposed Concepts; and before students of Park School, Indianapolis, January 30; title: A Is for Adam.

Bert H. Hefner, electrical engineer, Electro-Motive Division, before the winter session of the A.I.E.E., New York City, February 6; title: "2 in 1" Diesel Electric Locomotive.

W. H. Pfeiffer, supervisor, product finishes, Frigidaire Division, before the Dayton, Ohio, chapter of the American Society for Metals, February 11; title: Porcelain Enamel in the Home.

Personnel Development

J. C. Fetters, chief engineer, Turbine Engine Department, Allison Division, before the 38th Air Force-Aircraft Industry Conference, Palm Springs, California, January 12; title: Development and Test Teamwork.

Gordon Bowman, supervisor, Program Development Department, General Motors Institute, before the greater Detroit chapter of the American Society of Training Directors, November 17; title: An Engineering Approach to Program Development.

H. W. Lisiak, director of work standards, AC Spark Plug Division, Milwaukee plant, before the National Association of Suggestion Systems, Chicago, January 15; title: Employe Suggestion Program Through the Most Important Person, the Supervisor.

Charles J. Sahrbeck, administrative chairman, General Motors Institute, before the Plant Top Management Seminar, Riverside, California, January 22; title: Executive Development.

J. H. Anderson, project engineer, AC Spark Plug Division, before students of Wayne State University, Detroit, January 23; title: Developing Creativity and Creative Thinking in Engineering Graphics.

Norbert Sem, test engineer, AC Spark Plug Division, Milwaukee plant, before students of the Milwaukee School of Engineering, February 6; title: What Industry Expects of the Research Engineer.

Research

Richard C. Drutkowski, supervisor, Mechanical Development Department, GM Research Laboratories, before the national meeting of the A.S.M.E., New York City, December 4; title: Energy Losses of Balls Rolling on Plates.

G. P. Graham, isotope technician, **Farno L. Green** and **W. D. Cheek**, senior research physicists, GM Research Laboratories; and **C. Thomas Disney**, M.D., medical director, GM Technical Center, before the American Nuclear Society, Detroit, December 8; title: Radiation Characteristics of a SM-153 Photon Source.

Charles C. Gambill, project engineer, Frigidaire Division, before the Dayton, Ohio, chapter of the American Society for Metals, December 10; title: Use of Radioisotopes in Industry.

A Typical Problem in Industrial Engineering:

Improve Projection-Weld Quality Through Statistical Methods*

By GORDON L. WEBSTER
General Motors Institute

Projection welding is widely used in the fabrication of automobile hardware assemblies. Projection welds are usually tested for quality either by visual inspection or by impact test, such as that delivered by a hammer blow. Neither the impact test nor the visual inspection method provides a positive method for evaluating weld quality. The problem presented here is to investigate existing production conditions, relating to projection welding of automobile hardware assemblies, and then apply statistical methods of analysis to collected data in order to establish realistic standards for weld quality.

Instead of individual interpretation, use statistical analysis

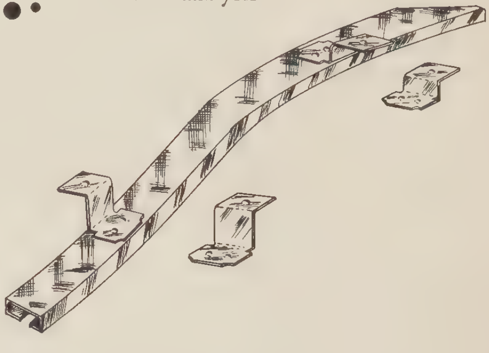


Fig. 1—Typical of the various automobile hardware assemblies utilizing projection welds is the guide channel assembly for a window regulator shown here. The brackets are projection welded onto the channel.

IN RESISTANCE welding the flow of current through metal generates heat as a result of electrical resistance, thus making it possible to join two separate parts into one by the fusion of metal at the point of contact. Projection welding is a type of resistance welding in which heat is localized by the use of projections, or "buttons," embossed on one of the parts to be welded. These projections are the means by which multiple welds can be produced in one machine cycle with a common electrode.

Projection weld quality is sometimes tested by an impact test, such as a hammer blow. An impact test, properly calibrated, detects defective welds, but over an extended period of time many borderline welds may be accepted as satisfactory. Another indication of projection weld quality may be provided by visual inspection of weld appearance, such as symmetry of weld spots, degree of heat discoloration, space between welded surfaces, or excessive "dimpling" of unmelted projections. Weld quality by visual inspection is subject to individual interpretations, since there are few established standards. Furthermore, there is limited knowledge of the relationship between the visual inspection factors involved and true weld quality.

A typical example of projection welding occurs in the high-volume fabrication of automobile hardware (Fig. 1). Since many of these parts function in concealed positions in highly inaccessible door and body panels, the cost of replacing defective parts either in the final assembly plant or in the field is far greater than the original production cost. Maintaining high levels of weld quality, therefore, becomes of the utmost importance.

At the GM Division which manufactures these hardware assemblies, engineers undertook the problem of establishing a program to assure weld quality. The approach was to obtain weld data free from individual interpretations and to use these data to apply methods of statistical quality control.

Initial analysis of the problem indicated the necessity for devising some sort of test to provide measurable evaluation of weld tensile strength. A non-destructive type of test was first thought desirable, and the possibility of using an ultrasonic method was considered. Investigation, however, led to the conclusion that this method, in its present state of development, would not be suitable for small projection welds of the type under study. It was finally decided to use flat test specimens and a tensile testing machine (Fig. 2). Such a test would provide the desired type of data and also permit a decision on the desirability of a special test fixture for the testing of welded production parts. A destructive test was performed on two specimens approximately once each hour over a six-day period. The data obtained were recorded on average and range charts (Fig. 3).

It was realized that weld strength was dependent not only upon such welding factors as machine-control settings and electrode condition but also upon projection height and zinc-plate thickness. It was decided, therefore, to check both the projection height and zinc-plate thickness against production specifications.

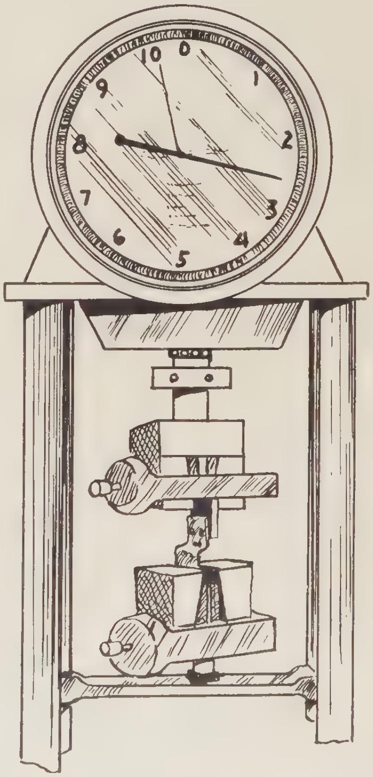


Fig. 2—To evaluate weld strength, a destructive test was performed on test specimens by a tensile testing machine similar to the one shown in the sketch.

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*This is a representative problem based on data taken from a General Motors Institute Fifth Year Project Study Report entitled "The Application of Statistical Quality Control to Resistance Welding Operations," prepared by Victor Abla while he was a G.M.I. co-op student sponsored by Ternstedt Division. Mr. Webster served as Institute Supervisor during preparation of the Report.

Sample No.	Each Item in Sample		Sample No.	Each Item in Sample		Sample No.	Each Item in Sample	
	X_1	X_2		X_1	X_2		X_1	X_2
1	1925	2000	19	1700	1525	37	1350	1800
2	1950	2000	20	1725	1500	38	1650	1700
3	1850	1950	21	1300	1100	39	1900	1825
4	1800	1950	22*	1350	1450	40	1850	1700
5	1850	1900	23	1750	1800	41	1700	1825
6	2000	2000	24	1700	1800	42	1525	1750
7	2100	2000	25	1625	1775	43	1700	1350
8	1750	1800	26	1500	1875	44	1800	1400
9	1975	1975	27	1575	1725	45	1475	1150
10	1550	1950	28	1850	900	46	1900	1800
11	2000	1600	29	1750	1600	47	1500	1850
12	1900	1800	30	1900	1950	48	1600	1825
13	1850	2100	31	1525	1525	49	1600	1825
14	1750	1850	32	1800	1900	50	1800	1675
15	1500	1450	33	1800	1650	51	1625	1900
16	1675	1650	34	1600	1800	52	1625	1650
17	1650	1475	35	1300	1700	53	1700	1725
18	1850	1825	36	1775	1625			

*Changed electrodes

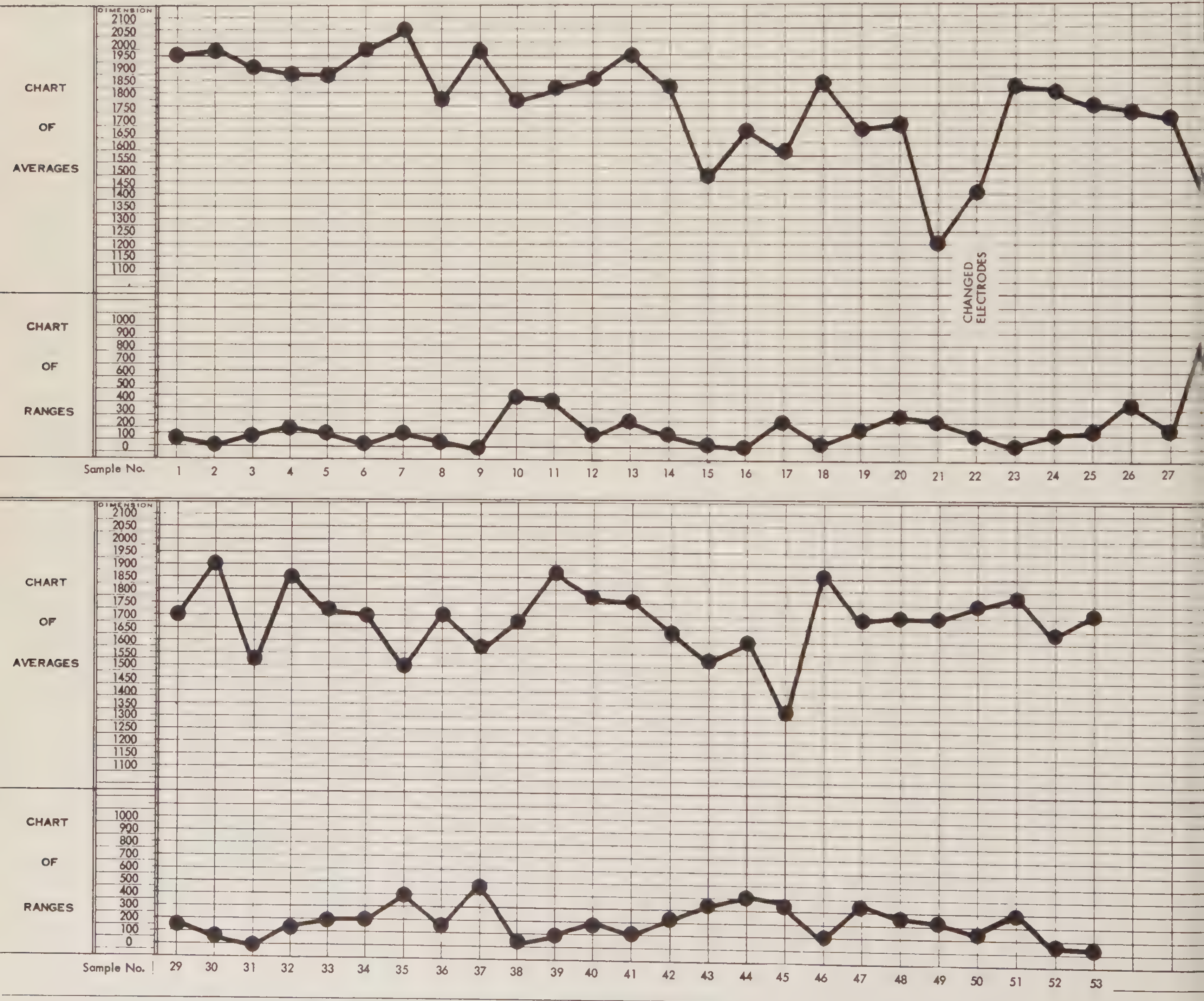
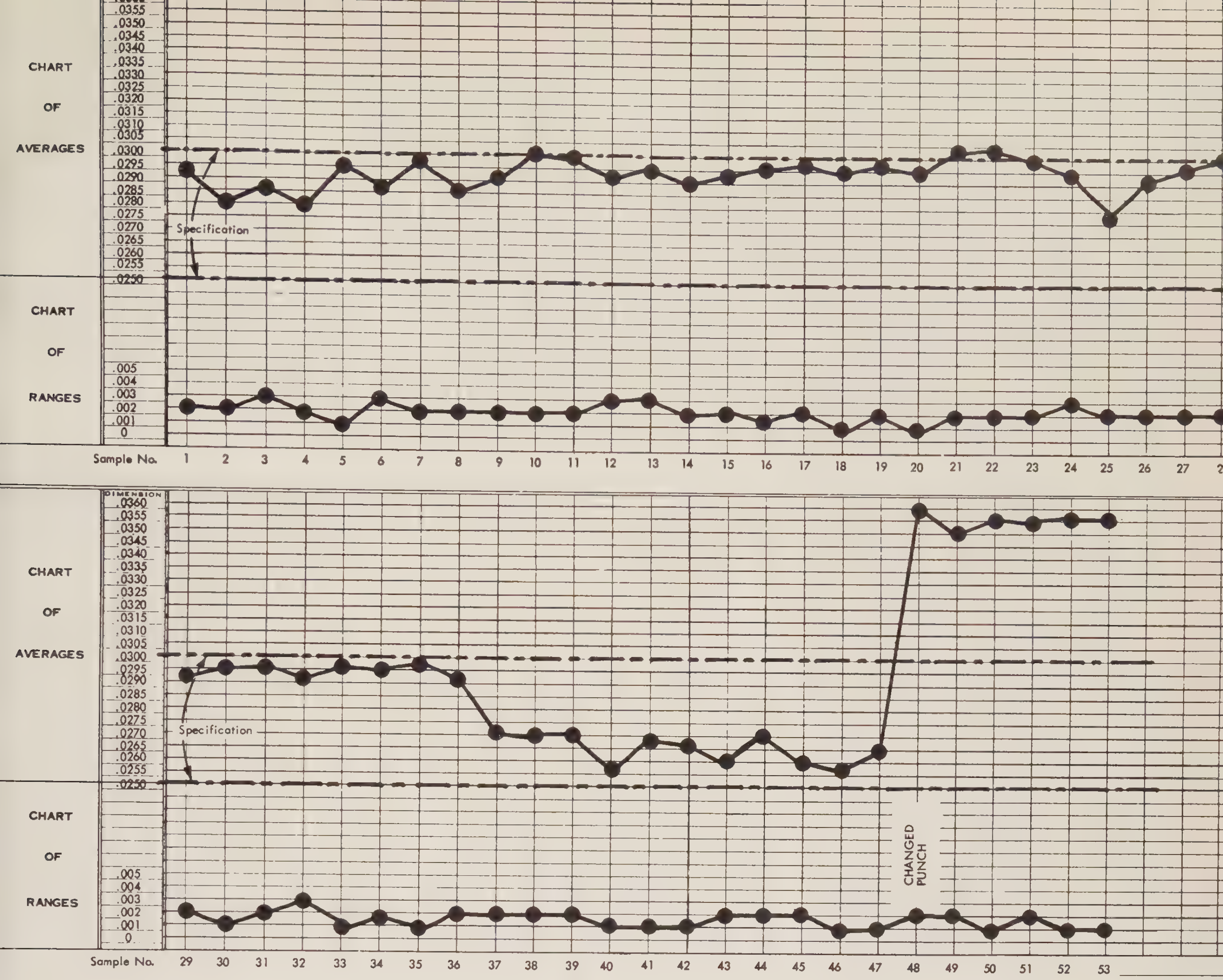


Fig. 3—Data obtained from the weld strength test were recorded on average and range charts. A total of 53 samples was used for the test, with each sample consisting of two specimens. Columns X_1 and X_2 of the table list tensile strength readings taken from the tensile testing machine to the nearest 25 lb.



Sample No.	Each Item in Sample			
	X_1	X_2	X_3	X_4
1	.028	.030	.029	.030
2	.027	.029	.027	.029
3	.028	.029	.027	.030
4	.028	.028	.029	.027
5	.029	.030	.029	.030
6	.029	.030	.029	.027
7	.029	.031	.029	.030
8	.028	.029	.028	.030
9	.029	.030	.028	.030
10	.030	.031	.029	.030
11	.030	.029	.030	.031
12	.029	.031	.028	.029
13	.028	.030	.029	.031
14	.028	.030	.028	.030
15	.028	.030	.029	.030
16	.029	.030	.029	.030
17	.029	.031	.029	.030
18	.029	.030	.029	.030
19	.030	.031	.029	.030
20	.029	.030	.029	.030
21	.029	.031	.030	.031
22	.031	.031	.029	.030
23	.030	.031	.029	.030
24	.028	.029	.031	.030
25	.027	.029	.028	.027
26	.030	.028	.029	.029
27	.030	.029	.031	.029
28	.030	.029	.030	.031
29	.030	.028	.030	.029
30	.030	.029	.030	.029
31	.030	.029	.030	.029
32	.031	.028	.030	.028
33	.030	.029	.030	.029
34	.029	.029	.031	.029
35	.030	.029	.030	.030
36	.030	.030	.029	.028
37	.026	.027	.027	.028
38	.027	.027	.026	.028
39	.027	.026	.027	.028
40	.026	.026	.025	.026
41	.026	.027	.027	.027
42	.026	.027	.026	.027
43	.026	.027	.025	.026
44	.026	.027	.027	.028
45	.025	.026	.026	.027
46	.025	.026	.026	.026
47	.026	.027	.026	.027
48*	.035	.037	.035	.036
49	.034	.036	.035	.035
50	.035	.036	.035	.036
51	.036	.035	.034	.036
52	.035	.036	.035	.036
53	.035	.036	.035	.036

*Changed punch.

Fig. 4—One factor affecting weld strength was projection height. Measurements were made on 53 samples, each sample consisting of four specimens. Data collected were plotted on the average and range charts shown here. The production specifications called for projection heights of 0.025 in. to 0.030 in. The table at the bottom lists projection height measurements (in inches) for each sample.

Measurement (inches)	No. of Occurrences
.00019	3
.00018	12
.00017	14
.00016	21
.00015	18
.00014	15
.00013	13
.00012	17
.00011	8
.00010	2

Table I—Zinc-plate thickness also was a factor affecting weld strength. A total of 123 measurements was made of plating thickness, and the frequency of occurrence of a given thickness was tabulated. The production specification called for a minimum zinc-plate thickness of 0.00011 in.

The projection-welded parts under consideration were zinc plated to provide corrosion resistance. The plating had to be burned off, however, before fusion of the parent metal was possible. The thickness of the zinc plate, therefore, had a definite bearing on weld quality.

Tests on projection height were made over the same period of time as the weld strength test. The data obtained also were recorded on average and range charts (Fig. 4). Zinc-plate thicknesses were determined by an electronic thickness tester. Data were collected to show the number of occurrences of a given zinc-plate thickness in test specimens (Table I).

Problem

The problem is to establish standards which will improve weld quality of projection welded assemblies. Measures of weld quality are to be established which will be free from individual interpretation. Solution to the problem will require the application of statistical methods of analysis to the data collected so that recommendations can be made to improve control of weld quality.

One approach to improving the control of weld quality and suggested recommendations will appear in the July-August-September 1959 issue of the General Motors Engineering Journal.

Bibliography

Related literature in this field includes the following:

Grant, E. L., *Statistical Quality Control* (New York: McGraw-Hill Book Co., Inc., 1952), pp. 510, 512, 513.

Solution to the Previous Problem:

Determine the Minimum Torque on an Automotive Engine Connecting Rod Bolt

Of major importance in the design of an automotive engine is the matter of connecting rod bolt fatigue failure. To prevent such failure, the bolts are pre-loaded to a greater tensile loading than will be encountered when the engine is in operation. This is the solution to the problem presented in the January-February-March 1959 issue of the General Motors Engineering Journal which required the determination of the minimum permissible torque required on the connecting rod bolt to assure that it would be pre-loaded to a value at least equal to or in excess of the operating load. The minimum torque was calculated to be *22.5 lb-ft*.

To determine the minimum torque required for the connecting rod bolt to assure that it will be pre-loaded to a value equal to or in excess of the operating load requires first an evaluation of the load cycle imposed on the rod bolts by the combined rotating and reciprocating masses. After the load cycle has been evaluated, the maximum load during the cycle can be compared to the known relationship between the torque applied to the connecting rod bolt and the actual tensile load in the bolt (Fig. 1). This comparison is for the purpose of determining the minimum value of bolt torque that can be tolerated if the bolt pre-load is to equal or exceed the operating load.

The first step in the solution is to calculate the maximum reciprocating inertia force F_I. Referring to Fig. 2, this force can be calculated as follows:

$$F_I = 2.84\,(10^{-5})\,(M)\,(n^2)\,(r)\,(\cos\Theta + \frac{r}{l}\cos 2\Theta)$$

where

F_I = maximum reciprocating inertia force (lb)

M = weight of piston assembly plus weight of upper end of connecting rod, including bolts = 2.34 lb

n = engine speed = 5,000 rpm

r = crank throw radius = 1.9375 in.

Θ = crank angle (degrees)

l = connecting rod center distance = 6.500 in.

Substituting known values into the preceding equation gives:

$$F_I = 2.84\,(10^{-5})\,(2.34)\,(5{,}000^2)\,(1.9375)\,(\cos 0° + \frac{1.9375}{6.500}\cos 0°)$$

$$F_I = 4{,}177 \text{ lb.}$$

The rotating inertia force F_R can be calculated as follows:

$$F_R = 3.41\,(10^{-4})\,(W)\,(n^2)\,(r)$$

where

F_R = rotating inertia force (lb)

W = rotating weight (lb).

The connecting rod cap is not considered as part of the rotating weight, since the centrifugal force of the cap and its bearing insert is supported by the crank pin journal. The rotating weight W, therefore, is equal to 0.715 lb. Substituting known values into the equation for rotating inertia force gives:

$$F_R = 3.41\,(10^{-4})\,(0.715)\,(5{,}000^2)\,(0.1615)$$

$$F_R = 984.2 \text{ lb.}$$

The total inertia load on one connecting rod bolt is one half the reciprocating and rotating inertia forces, or

$$\text{Total inertia load} = \frac{4{,}177 + 984.2}{2}$$

$$\text{Total inertia load} = 2{,}580.6 \text{ lb.}$$

Referring to the low limit bolt curve (Fig. 1) of the bolt torque versus bolt

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Reciprocating and rotating inertia forces must be found

tensile strength relationship, it can be seen that when using the total inertia load value of 2,580 lb as the ordinate a bolt torque of approximately 22.5 lb-ft is required.

The torque specifications for the connecting rod nuts called for 45 lb-ft of torque. This allows for a 100 per cent torque tightness safety factor and results in a minimum bolt tensile load of 7,500 lb. This is still considerably less than the minimum yield strength of the bolt material which was specified as 11,500 lb.

Summary

This problem illustrates the application of basic principles to the threaded bolt-type fastener. It is very important for the design engineer to keep in mind the factors influencing the selection of material, design, and torque specifications of a bolted fastener. With such an understanding of the factors involved it then becomes a relatively simple matter to arrive at the correct bolt size and torque specifications for efficient fastenings.

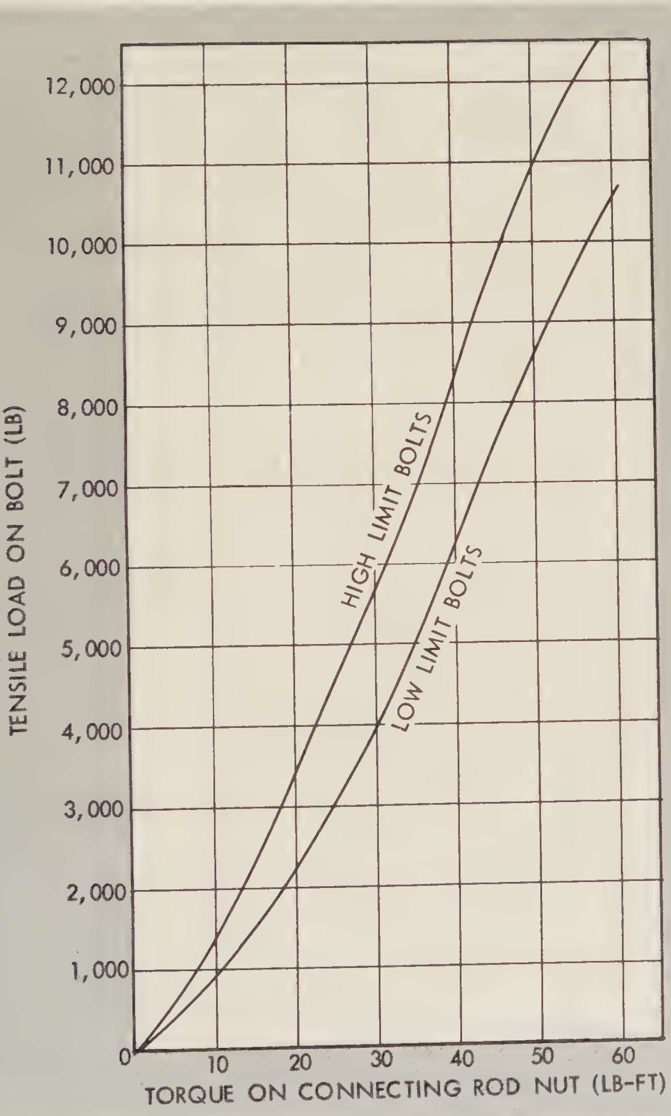


Fig. 1—Plotted here is the relationship between the torque applied to the connecting rod and the actual tensile load in the bolt. The area of the curves between the high limit bolts and the low limit bolts denotes the range of tensile loading encountered when an investigation was made regarding bolt tension versus applied torque for a number of samples. This rather wide range of variations is to be expected due to the many variables encountered in the application of threaded fasteners.

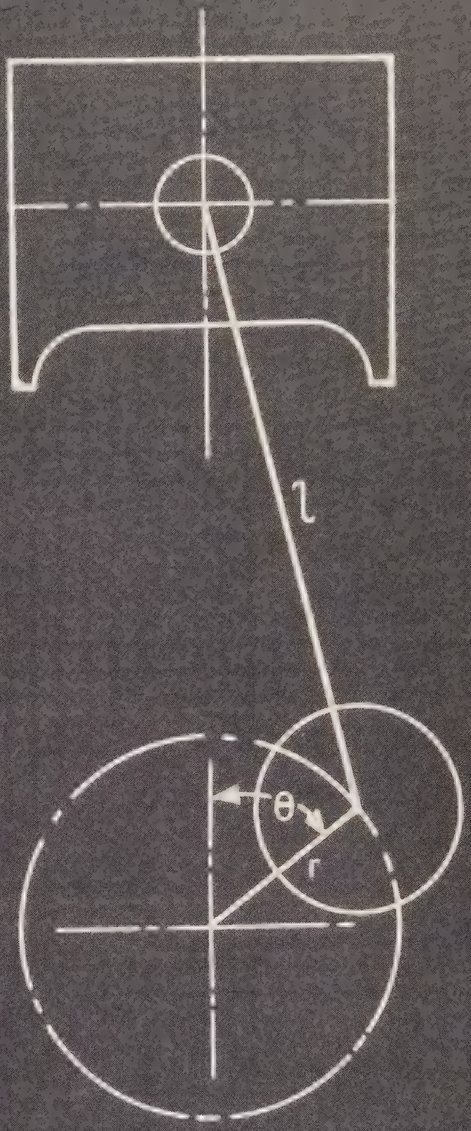
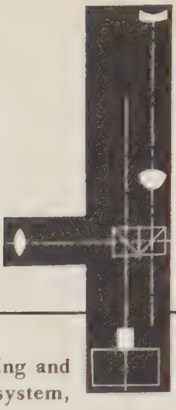


Fig. 2—The acceleration of the piston, rings, piston pin, and small end of the connecting rod is a function of the rotational speed of the crankshaft and the r/l ratio of the crank throw radius r and connecting rod center distance l.

Solution to the Previous Problem:

Determine the Optical Characteristics of a Beam Splitting Optical System



By STANLEY A. FOTTLER
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The design of optical systems for industrial applications presents many interesting and challenging problems. Once the designer has established what is required of the system, it then remains to design the system to be as compact and flexible as possible and still meet the requirements. This is the solution to the problem presented in the January-February-March 1959 issue of the GENERAL MOTORS ENGINEERING JOURNAL. The optical system under consideration was to be designed to provide a one-to-one image for the purpose of taking pictures with a movie camera and simultaneously magnify the image for viewing purposes. The design of the system is achieved through the application of basic principles of geometrical optics.

A typical application of basic principles of geometrical optics

THE grinding of a single element lens for a specific purpose can be accomplished if the lens radii of curvature, diameter, and index of refraction of the lens material are given. Since many different radii combinations can be used for a lens of a given focal length, the radii which will minimize spherical aberration and coma in the specific application must be determined.

The relationship between the radii of curvature of a lens is called the shape factor q and is expressed as follows[1]:

$$q = \frac{r_2 + r_1}{r_2 - r_1} \qquad (1)$$

where

r_1, r_2 = radii of curvature.

The shape factor for minimum spherical aberration q_a (third order theory) is a

Correction to the Previous Problem

In the statement to the problem presented in the January-February-March issue, the magnification for Lens No. 3 was incorrectly stated as plus five. The magnification for Lens No. 3 should be minus five.

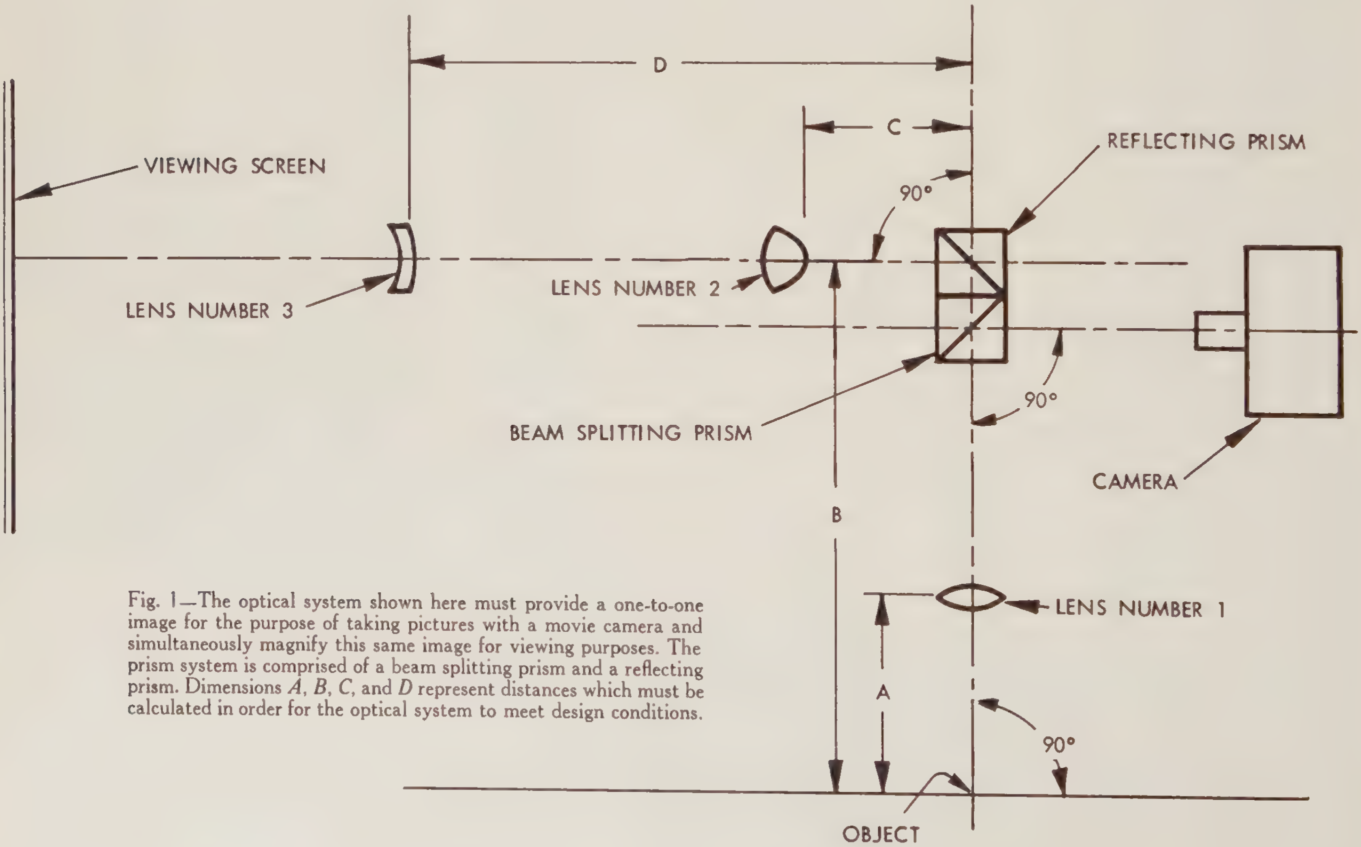


Fig. 1—The optical system shown here must provide a one-to-one image for the purpose of taking pictures with a movie camera and simultaneously magnify this same image for viewing purposes. The prism system is comprised of a beam splitting prism and a reflecting prism. Dimensions A, B, C, and D represent distances which must be calculated in order for the optical system to meet design conditions.

CALCULATIONS FOR FIRST LENS SURFACE

	h = 1.5 cm	h = 1.0 cm	h = 0 cm
Log h	0.17609	0.00000	
Colog r_1	9.10541 − 10	9.10541 − 10	
Log sin ϕ	9.28150 − 10	9.10541 − 10	
Log n	0.00000	0.00000	
Colog n_1	9.81730 − 10	9.81730 − 10	
Log sin ϕ_1	9.09880 − 10	8.92271 − 10	
ϕ	11°1′47″	7°19′25″	0.19121 radians
ϕ_1	7°12′44″	4°48′4″	0.12557 radians
Θ	3°49′3″	2°31′21″	0.06564 radians
Colog sin Θ	1.17667	1.35650	1.18283
Log sin ϕ_1	9.09880 − 10	8.92271 − 10	9.09880 − 10
Log r_1	0.89459	0.89459	0.89459
Log $(r_1 - S_{I1})$	1.17006	1.17380	1.17622
$r_1 - S_{I1}$	− 14.793	− 14.921	− 15.005
S_{I1}	22.638	22.766	22.850
r_1 = 7.845 cm		n = 1.000	n_1 = 1.5230

Table I—Tabulated here is the step-by-step solution of equations (9) through (12) for the first lens surface.

function of the index of refraction of the lens material and the magnification required, or

$$q_a = \frac{-2(n^2 - 1)}{n + 2}(p) \qquad (2)$$

where

n = index of refraction
p = position factor.

The position factor p is defined by the following relationship:

$$p = \frac{S_I - S_O}{S_I + S_O} = \frac{m - 1}{m + 1} \qquad (3)$$

where

S_O = object distance
S_I = image distance
m = geometric magnification, or the ratio of the object to the image distance.

The shape factor for minimum coma q_c (third order theory) is a function of the refractive index and the position factor, or

$$q_c = -\frac{G}{W}(p) \qquad (4)$$

where

G = a constant = $\dfrac{3(2n + 1)}{4n}$

W = a constant = $\dfrac{3(n + 1)}{4n(n - 1)}$.

Lens No. 1

The preceding relationships can now be applied to determine the following factors for Lens No. 1:

- Shape factor for minimum aberration and coma
- Object and image distances
- Principal planes
- Location of lens center
- Usable diameter of lens.

Shape Factor

The geometric magnification for Lens No. 1 was given as one. The position factor p, therefore, will equal

$$p = \frac{m - 1}{m + 1} = \frac{1 - 1}{1 + 1} = 0.$$

Substituting this value for position factor into equations (2) and (4) gives the shape factor for both minimum spherical aberration and coma as zero.

The focal length f of Lens No. 1 was given as 75 mm. The index of refraction for common optical quality glass is 1.523. Knowing this information, plus the value

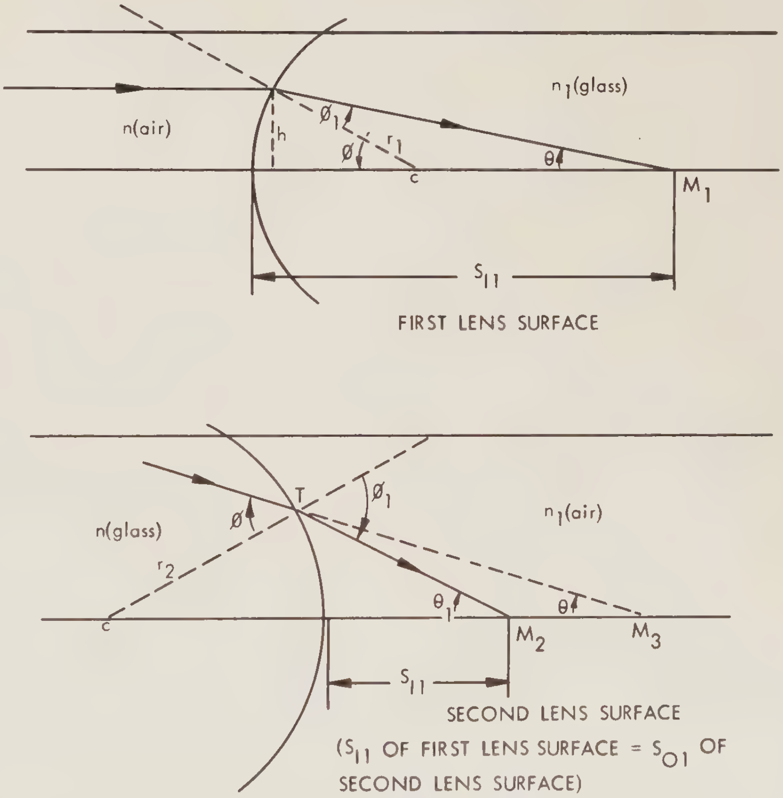


Fig. 2—The terms used in equations (9) through (12) are defined here in the top diagram. The bottom diagram defines the terms used in equations (13) through (16). In both diagrams, the letter c represents the center of the radius of curvature for the lens surface. Also, M_1 is the point of focus for the ray that passes through the first lens surface and M_2 is the point of focus for the ray that passes through the second lens surface. In the bottom diagram, the angles ϕ, ϕ_1, Θ, and Θ_1 are negative. The sum of the angles in triangle M_2TM_3 are equal to 180°, or $[(-\phi_1)-(-\phi)] + [\pi - (-\Theta_1)] + (-\Theta) = \pi$.

CALCULATIONS FOR SECOND LENS SURFACE

	$\Theta = 3°49'3''$	$\Theta = 2°31'21''$	$\Theta = 0$
$r_2 + S_{O1}$	29.583	29.711	29.795
Log $(r_2 + S_{O1})$	1.47104	1.47294	1.47414
Colog r_2	9.10541 − 10	9.10541 − 10	9.10541 − 10
Log sin Θ	8.82333 − 10	8.64341 − 10	8.81717 − 10
Log sin ϕ	9.39978 − 10	9.22176 − 10	9.39672 − 10
Log n	0.18270	0.18270	0.18270
Colog n_1	0.00000	0.00000	0.00000
Log sin ϕ_1	9.58248 − 10	9.40446 − 10	9.57942 − 10
ϕ_1	22°28'50"	14°42'8"	0.38237 radians
Θ	3°49'3"	2°31'31"	0.06658 radians
ϕ	14°32'25"	9°35'33"	0.25106 radians
$\Theta_1 = (\phi_1 + \Theta - \phi)$	11°49'28"	7°34'53"	0.19789 radians
Colog sin Θ_1	0.68844	0.87683	0.70355
Log sin ϕ_1	9.58248 − 10	9.40446 − 10	9.57942 − 10
Log r_2	0.89459	0.89459	0.89459
Log $(r_2 - S_{I1})$	1.16551	1.17588	1.17756
$r_2 - S_{I1}$	− 14.639	− 14.993	− 15.051
S_{I1}	6.794	7.148	7.206
δS_{I1}	0.412 cm	0.058 cm	0 cm
$r_2 = -7.845$ cm	$n = 1.5230$	$n_1 = 1.00000$	

Table II—Tabulated here is the step-by-step solution of equations (13) through (16) for the second lens surface.

for shape factor, allows the radii of curvature to be calculated as follows:

$$r_1 = \frac{2f(n-1)}{q+1} \qquad (5)$$

$$r_2 = \frac{2f(n-1)}{q-1} \qquad (6)$$

where

r_1 = radius of first surface
r_2 = radius of second surface
f = focal length for Lens No. 1 = 75 mm
q = shape factor = 0
n = index of refraction = 1.523.

Substituting known values into equations (4) and (5) gives

$$r_1 = +78.45 \text{ mm}$$
$$r_2 = -78.45 \text{ mm.}$$

Object and Image Distances for Lens No. 1

The object distance S_{O1} and the image distance S_{I1} for Lens No. 1 can be calculated as follows:

$$\frac{1}{f} = \frac{1}{S_{O1}} + \frac{1}{S_{I1}}.$$

However,

$$S_{O1} = S_{I1}.$$

Therefore,

$$\frac{1}{f} = \frac{2}{S_{O1}}.$$

The focal length f of Lens No. 1 is equal to 75 mm. The object and image distances for Lens No. 1, therefore, are equal to 150 mm.

Principal Planes

The principal planes for r_1 and r_2 can be calculated as follows:

$$H = \frac{r_1(t)}{[n(r_1 + r_2) - t(n-1)]} \qquad (7)$$

$$H_1 = \frac{r_2(t)}{[n(r_1 + r_2) - t(n-1)]} \qquad (8)$$

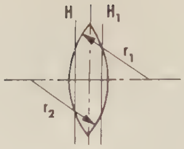
where

H = principal plane dimension for r_1
H_1 = principal plane dimension for r_2
t = thickness of Lens No. 1 = 9 mm.

Substituting known values into equations (7) and (8) gives

H = 0.271 cm, or 2.71 mm
H_1 = 0.271 cm, or 2.71 mm.

The principal planes are measured from the lens surfaces toward the center of the lens, as indicated in the following diagram.



Location of Lens Center

To determine the location of the center of Lens No. 1 to the nearest millimeter (dimension A, Fig. 1), one half the distance between the principal planes must be added to the object distance.

The thickness of Lens No. 1 is 9 mm. The principal planes have been calculated to be $H + H_1 = 5.42$ mm. The distance between $H + H_1$ is equal to 3.58 mm. The location of the center of Lens No. 1, or dimension A in Fig. 1, is 151.8 mm.

Usable Diameter of Lens No. 1

To determine the usable diameter of Lens No. 1 so that the deviation from the focal length does not exceed 0.5 mm, the following equations must be solved[1]:

$$\sin \phi = \frac{h}{r_1} \qquad (9)$$

$$\sin \phi_1 = \frac{n}{n_1} (\sin \phi) \qquad (10)$$

$$r_1 - S_{I1} = r_1 \left(\frac{\sin \phi_1}{\sin \Theta} \right) \qquad (11)$$

$$\Theta = \phi_1 - \phi. \qquad (12)$$

The terms in equations (9) through (12) are defined in Fig. 2 (top).

To determine the focal length deviation, it is necessary to assume parallel light entering the lens and to calculate the focal distance for rays of light at heights of 1.5 cm, 1.0 cm, and 0.0 cm above the axes of the lens. The solution to equations (9), (10), (11), and (12) for these ray heights is found in Table I and applies to the first surface of the lens. Thus, S_{I1} becomes the object for the second surface.

For the second surface, the following equations apply:

$$\sin \phi = \frac{r_2 + S_{O1}}{r_2} (\sin \Theta) \qquad (13)$$

$$\sin \phi_1 = \frac{n}{n_1} (\sin \phi) \qquad (14)$$

$$r_2 - S_{I1} = r_2 \left(\frac{\sin \phi_1}{\sin \Theta_1} \right) \qquad (15)$$

$$\Theta_1 = \phi_1 + \Theta - \phi. \qquad (16)$$

The terms in equations (13) through (16) are defined in Fig. 2 (bottom). Also, Table II gives the solution to equations (13) through (16).

The deviation of the image distance for the three rays of light considered can be denoted as δS_{I1}. Since parallel light was assumed, S_{I1} for the second lens surface now becomes equal to the focal length of the lens. Therefore, δS_{I1} gives the deviation of the focal length as the distance from the optical axis of the lens increases. By plotting these values for ray height against the deviation in focal length (Fig. 3) the usable diameter of the lens can be found. The usable diameter of Lens No. 1, as determined from such a plot, is found to be 16 mm.

Lens No. 2

The magnification m for Lens No. 2 was given as six. The position factor p, therefore, for Lens No. 2 is equal to

$$p = \frac{m-1}{m+1} = \frac{5}{7} = 0.714.$$

Shape Factors for Lens No. 2

Knowing the position factor allows the shape factors to be calculated. Applying equation (2), the shape factor q_a for minimum spherical aberration is equal to -0.535. The shape factor q_c for minimum coma is determined by applying equation (4) as follows:

$$q_c = -\frac{G}{W}(p)$$

$$q_c = -\left(\frac{1.99}{2.37}\right)(0.714) = -0.60.$$

The shape factors are not equal. To obtain the least effect of both aberrations, therefore, a point must be chosen between the two calculated shape factors. For this solution, a shape factor q of -0.57 was chosen.

The focal length f for Lens No. 2 was given as 100 mm. Knowing the focal length and the shape factor q makes it possible to calculate the radii of curvature for Lens No. 2. By applying equation (5), the radii of curvature for the first surface is equal to

$$r_1 = \frac{2f(n-1)}{q+1} = 243 \text{ mm.}$$

Applying equation (6) gives the radii of the second surface as

$$r_2 = \frac{2f(n-1)}{q-1} = -66.7 \text{ mm.}$$

Principal Planes for Lens No. 2

For all problems in optical image formation it is always good practice to construct a principal ray diagram. From a ray diagram for this particular problem (Fig. 4), using calculated values for its construction, the maximum usable diameter for Lens No. 2 is found to be four cm. Also, the thickness t for Lens No. 2 is found to be four mm.

Knowing the lens thickness and radii of curvature allows the principal planes for Lens No. 2 to be calculated. From equation (7), the principal plane H for r_1 is 2.07 mm. By applying equation (8) the principal plane H_1 for r_2 is found to be 0.57 mm.

Object and Image Distances

The ratio of the object distance S_{O2} to the image distance S_{I2} for Lens No. 2 is six to one. The object and image distances can be calculated as follows:

$$\frac{1}{f} = \frac{1}{S_{O2}} + \frac{1}{S_{I2}}$$

where

f = focal length for Lens No. 2 = 100 mm.

Therefore,

$$S_{O2} = 116.67 \text{ mm}$$
$$S_{I2} = 700 \text{ mm.}$$

Lens No. 3

As with Lenses No. 1 and No. 2, the position factor p for Lens No. 3 is calculated from the magnification m, which is minus five. The position factor for Lens No. 3 is equal to

$$p = \frac{3}{2} = 1.50.$$

Shape Factor for Lens No. 3

Equations (2) and (4) are applied to determine the shape factor q_a for minimum spherical aberration and the shape factor q_c for minimum coma.

$$q_a = -1.13$$
$$q_c = -1.26.$$

As with Lens No. 2, the shape factors q_a and q_c for Lens No. 3 are not equal. A point must be chosen between these two shape factors, therefore, to obtain the least effect of both aberrations. For Lens No. 3, a shape factor q of -1.20 was chosen.

Principal Planes for Lens No. 3

The focal length of Lens No. 3 was given as -200 mm. Substituting this value for f into equations (5) and (6), along with the value for shape factor q, gives the following values for the radii of curvature for Lens No. 3:

$$r_1 = +1{,}046 \text{ mm}$$
$$r_2 = +95.0 \text{ mm.}$$

From the principal ray diagram (Fig. 4), the diameter of Lens No. 3 is found to be 60 mm.

The thickness t of Lens No. 3 was given as six mm. Substituting this value for lens thickness and the values for radii of curvature into equations (7) and (8) gives the following values for the principal planes for Lens No. 3:

$$H = 3.6 \text{ mm}$$
$$H_1 = 0.3 \text{ mm.}$$

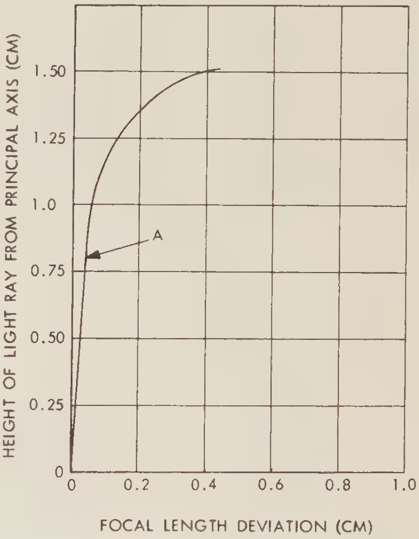


Fig. 3—To determine the usable diameter for Lens No. 1, values obtained for rays of light at heights of 1.5 cm, 1.0 cm, and 0.0 cm above the axes of the lens are plotted against focal length deviation, as shown here. The focal length deviation for Lens No. 1 was not to exceed 0.5 mm. Point *A* on the graph represents the radius of Lens No. 1 for the specified focal length deviation. Therefore, the usable diameter is 16 mm.

Object and Image Distances

The magnification for Lens No. 3 is minus five. The object distance S_{O3} and image distance S_{I3}, therefore, are calculated as follows:

$$S_{I3} = 5S_{O3}$$

$$\frac{1}{f} = \frac{1}{S_{O3}} + \frac{1}{5S_{O3}}$$

where

f = focal length = -200 mm.

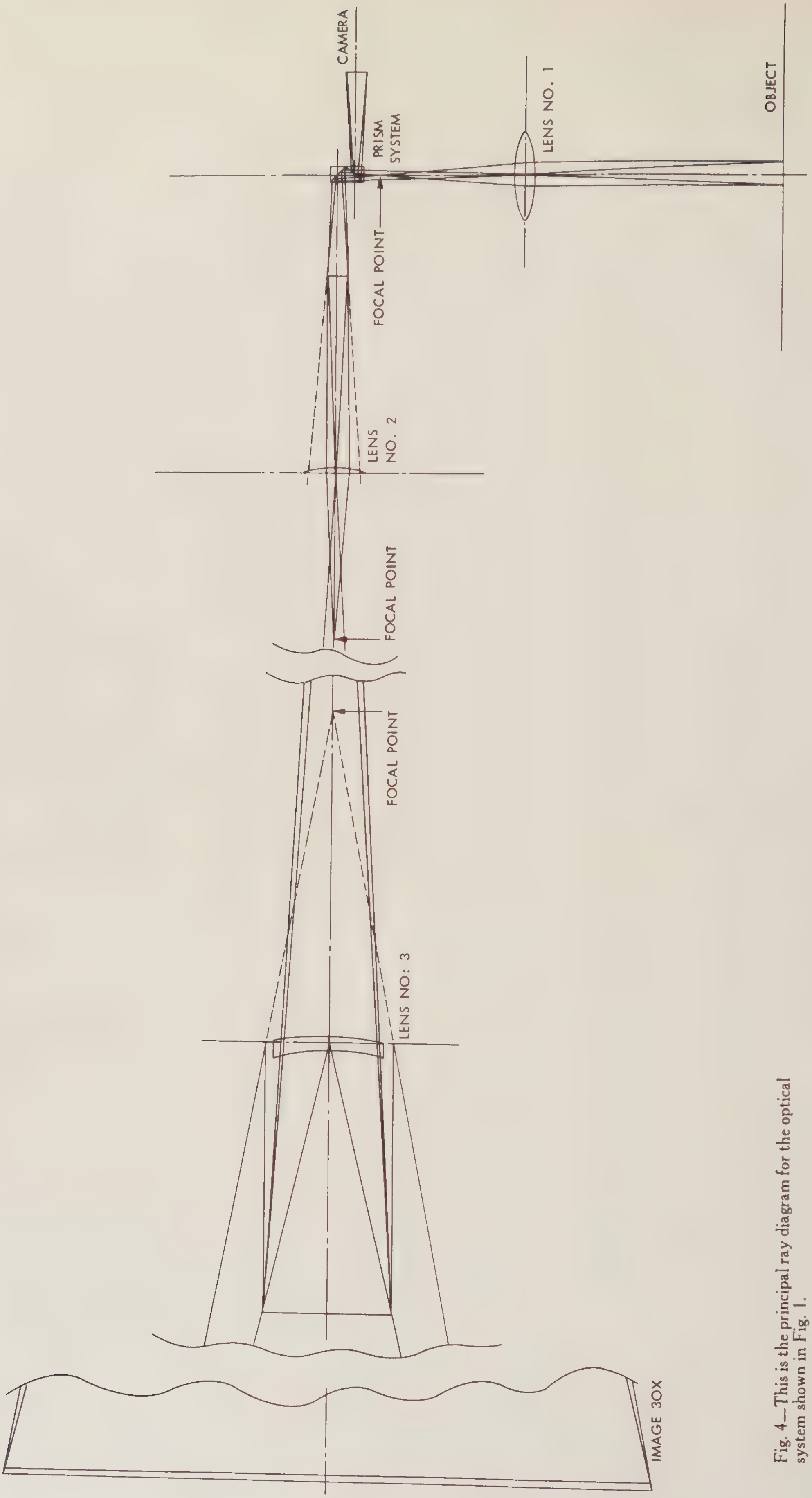


Fig. 4—This is the principal ray diagram for the optical system shown in Fig. 1.

The object distance S_{O3} will be negative for Lens No. 3 because the object for this lens is virtual. Therefore,

$$S_{O3} = -\ 160 \text{ mm}$$
$$S_{I3} = +\ 800 \text{ mm.}$$

Location of Lenses 2 and 3

The location of Lenses No. 2 and 3 has been left until this point in the solution because of the effect of the glass prism on the path length. Since light travels at a lower velocity in glass than in air, the effect of placing a piece of glass in the optical path is to increase the path length.

The equivalent air thickness for the prism can be expressed by the following relationship[2]:

$$\text{equivalent air thickness} = \frac{T}{N}$$

where

T = thickness of prism = 25.4 mm
N = index of refraction for prism.

The true image distance for Lens No. 1, S_{I1t}, is equal to

$$S_{I1} + T(1 - \frac{1}{N}).$$

The true image distance for the camera, S_{IC}, is equal to

$$S_{IC} = 150 + 25.4(1 - \frac{1}{1.523}) = 158.7 \text{ mm.}$$

The true image distance for the magnified image path, S_{IM}, is equal to 167.4 mm.

The location of Lens No. 2, therefore, becomes the sum of the object and corrected image distances for Lens No. 1, plus the distance between the principal planes of Lens No. 1, plus the object distance for Lens No. 2. Referring to Fig. 1, the location of Lens No. 2 is equal to

$$B + C = 437.7 \text{ mm.}$$

The location for Lens No. 3 is equal to B plus C plus the image distance for Lens No. 2 minus the object distance for Lens No. 3, or

$$B + D = 979.1 \text{ mm.}$$

Complete Optical System

The total path length for the camera image is equal to the object distance, plus the distance between the principal planes, plus the corrected image distance for Lens No. 1, or

$$150 + 3.6 + 158.7 = 312.3 \text{ mm.}$$

The total path length for the magnified image is equal to the sum of all object and image distances. This includes the compensated image distance for Lens No. 1 and the distance between all principal planes. In the case of Lens No. 3, it must be remembered that the object is virtual. The total path length for the magnified image is equal to 1,781 mm.

It will be noted that the distances between principal planes of the three lenses are not very large. When larger fields of view are used, however, which is generally the case, these distances become appreciable.

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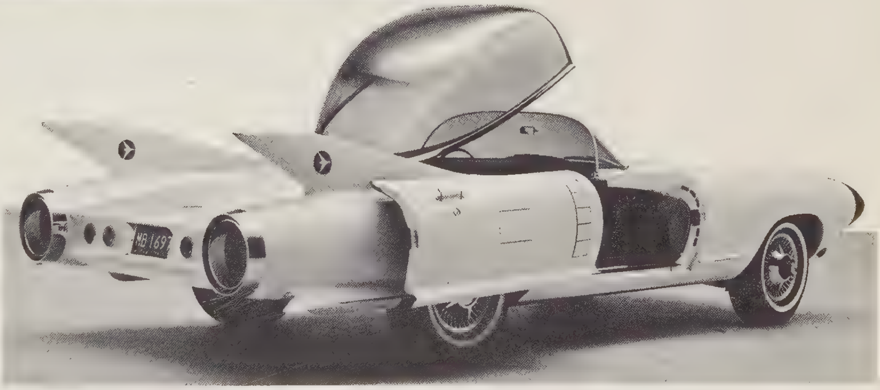
2. Habell, K. J., and Cox, A., *Engineering Optics*, (London: Pitman and Sons, Ltd., 1948), pp. 11-12.

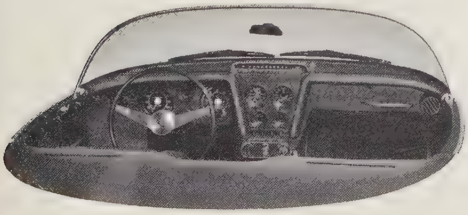
GM ENGINEERS AND STYLISTS DEVELOP THIRTY-EIGHTH EXPERIMENTAL CAR



Since 1938, GM engineers and stylists have collaborated in the design and development of 38 experimental cars. The latest in the series is the Cadillac Cyclone, developed by the GM Styling Staff in cooperation with Cadillac Motor Car Division. Various component contributions were made by the Engineering Staff and seven GM Divisions.

Developed as an experimental laboratory on wheels to test new ideas in automotive styling and engineering, the two-passenger, steel-bodied Cyclone has a one piece, laminated plastic passenger canopy. The power-operated canopy, silver coated to deflect the sun's rays, is hinged at the rear. When either door is opened, the canopy lifts automatically to afford passenger entrance and, when not in use, folds back and disappears beneath the surface of the rear deck.

An unusual feature is the operation of the doors. At the touch of a button on either side, the door moves outward from the body three inches. The driver then slides the door back along the side of the car for easy entrance.



The Cyclone is powered by a 1959 Cadillac 325 hp engine, mounted in the front. The engine features a new low profile carburetor, cross flow aluminum radiator, and twin fans. The muffler and exhaust system is located in the engine compartment with the exhaust outlets just ahead of the front wheels. An experimental Hydra-Matic automatic transmission and final drive assembly are mounted behind the passenger compartment.

The front suspension of the Cyclone incorporates standard 1959 Cadillac air suspension units. The power brake system uses an air servo instead of the conventional vacuum servo, with air being supplied from the air suspension system. The steering system uses a rotary valve power steering gear with variable ratio added. Front wheels and brake drums are integral castings and feature improved cooling for increased braking power. Other features include inboard-mounted rear brakes; 14-in. cast aluminum wheels; and combined heating and refrigeration units housed in cowl sections on either side of the passenger compartment doors.

Overall length of the Cyclone is 196.9 in. and the wheelbase is 104 in. Overall height is 44 in. at top of the passenger canopy.

Contributors to April-May-June 1959 Issue of GENERAL MOTORS ENGINEERING JOURNAL

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co-contributor of "A Radioisotopic Study of Leveling in Bright Nickel Electroplating Baths," is a senior research chemist in the Electrochemistry and Polymers Department of the GM Research Laboratories. His present activities include research on the fundamentals of electrodeposition processes, the use of radioactivity to study the mechanism of leveling, optical investigations of the cathode film, adsorption studies with addition agents, and transfer studies with the rotating plate. His previous projects included study of the cathode film with the shadowgraph and interferometer.

Dr. Beacom joined GM in 1957 after experience in industrial research and in science education, including a professorship in chemistry at the Teachers College of Connecticut. He has had papers published in the *Journal of the Electrochemical Society* and *Nature* magazine, and has written several bulletins on science education.

Dr. Beacom received the B.S. degree from Mount Union College in 1934, the M.S. degree from the University of Michigan in 1946, and the Ph.D. degree from the University of Connecticut in 1954. He is a member of Phi Lambda Upsilon and Sigma Xi honor societies, and holds membership in the American Chemical Society, the American Electroplaters Society, the American Association for the Advancement of Science, and serves as secretary-treasurer of the Detroit Section of the Electrochemical Society.

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contributor of "A New Product Design: Evolution of a 6,000-kw Generating Plant for Peaking and Reserve Capacity," is chief engineer of Electro-Motive Division, La Grange, Illinois.

Mr. Brownell was graduated from the Massachusetts Institute of Technology in 1935, receiving the Bachelor of Science in Electrical Engineering degree. He joined General Motors in the same year as a test engineer with the Delco Products Division in Dayton, Ohio. He was transferred to Electro-Motive in 1937 as a junior electrical engineer. Subsequent promotions included assistant electrical engineer in 1939 and assistant staff engineer in 1943. He became chief electrical engineer in 1946, and was responsible for the design and development of traction motors, generators, and electrical control apparatus for Diesel locomotives.

Mr. Brownell was promoted to assistant chief engineer in 1953, and was in charge of design and development of the complete product line. He was appointed to his present position in 1955.

STEVE CENKO,

co-contributor of "The Development and Use of a Modified V-8 Engine for Student Experimentation," is head of the Mechanical Engineering Laboratory Section at General Motors Institute. He is responsible for developing experimental laboratory problems which are integrated with design classes and which utilize present day laboratory techniques for the solution of engineering problems.

Mr. Cenko joined General Motors in 1944 as a G.M.I. co-op student sponsored by the Detroit Transmission Division. In 1949, after receiving the B.M.E. degree from G.M.I., he was made a junior engineer at Detroit Transmission and did developmental work on automatic transmissions. The following year he joined the faculty of G.M.I. as head of the transmission section of the Product Service Department. In 1955 he was transferred to the Product Engineering Department and assumed his present position. His teaching experience has been in the fields of internal combustion engines and their accessories as well as the automobile chassis and chassis units.

Mr. Cenko is a member of the American Society for Engineering Education. He is presently completing work for a master's degree at Wayne State University.

PAUL J. ETHINGTON,

contributor of "Premature Disclosures of Technical Developments," and coordinator of this issue's "Notes About Inventions and Inventors," is a patent attorney in the General Motors Patent Section, Detroit Office. His current responsibilities include the handling of patent applications for inventions (especially patent matters involving electronics) and handling infringement investigations for new products.

Mr. Ethington joined GM in 1952 as a patent searcher in the Washington Office of the Patent Section. From 1953 to 1954 he was with Collins Radio Company as patent attorney. He then rejoined GM in the Detroit Office of the Patent Section as patent attorney. His experience also includes patent work with the Bendix Aviation Corporation.

Mr. Ethington received the Bachelor of Science in Electrical Engineering degree from Iowa State College in 1948, and he is a member of Eta Kappa Nu, electrical engineering honorary society. He attended George Washington University and received the Juris Doctor degree in 1953. He is a registered patent attorney, a member of the Bar in Michigan, the District of Columbia, and Iowa, and a member of the Michigan Patent Law Association.

STANLEY A. FOTTLER

co-contributor of the problem "Determine the Optical Characteristics of a Beam Splitting Optical System," and the solution appearing in this issue, is a physicist with the Process Development

Section of the GM Process Development Staff.

Mr. Fottler joined GM in 1954 as a routine physicist in the Electronics Department of the Process Development Section. He was advanced to his present position in 1957. Among his past projects were the development of an automatic method using optical means to inspect metal surfaces for defects and the development of a method for non-destructively analyzing gas contained in a sealed-glass unit. His present responsibilities include the development of measurement techniques using such means as optics, radioisotopes, and sound.

Mr. Fottler was granted the B.S. degree in education from Western Illinois State University in 1953. Prior to entering this University, he attended Monmouth College.

ROBERT H. KOHR,

contributor of "The Application of Mathematics to a Basic Study of Automobile Control and Stability Problems," is a supervisor of the Vehicle Dynamics Section of GM Research Laboratories' Engineering Mechanics Department. His present responsibilities include supervision of analysis and computer simulation of automobile ride and handling characteristics.

Mr. Kohr joined the Research Laboratories in 1954 as a research engineer in the Engineering Mechanics Department. Two years later he was promoted to senior research engineer. He assumed his present position in 1957. One of his previous major projects was the design and construction of hydraulic accelerometers for use in an experimental steering gear.

Mr. Kohr received the B.S.E. (physics) degree in 1950 from the University of Michigan. The following year he was granted the M.S.E. (engineering mechanics) degree. Prior to joining the Research Laboratories, Mr. Kohr was employed by the Holley Carburetor Company as a project engineer.

The technical affiliations of Mr. Kohr include membership in the Society of Automotive Engineers and the Midwestern Simulation Council. He also is a member of Tau Beta Pi, honorary society.

CARL KLIGMAN,

co-contributor of the problem "Determine the Optical Characteristics of a Beam Splitting Optical System," and the solution appearing in this issue, is a physicist with the Electronics Department of the Process Development Section, GM Process Development Staff.

Mr. Kligman received the Bachelor of Science degree in 1941 from Hillsdale College. The following year he was granted the Master's degree from the University of Michigan.

Prior to joining GM in 1957, Mr. Kligman had experience as a mathematics instructor at Franklin Technical Institute, Boston; as an associate professor of mathematics at Hillsdale College; and as a physicist with the U. S. Rubber Company.

His present responsibilities include the development of new techniques for the application of light (optics) and sound for measurements and process control.

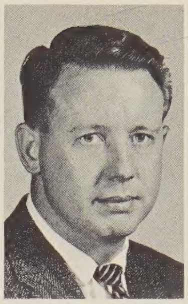
The technical affiliations of Mr. Kligman include membership in the American Physical Society.

ELWOOD K. HARRIS,

co-contributor of "The Development and Use of a Modified V-8 Engine for Student Experimentation," is chairman of the Product Engineering Department at General Motors Institute. In this position he is responsible for correlating departmental assignments in the general areas of engineering drawing, descriptive geometry, thermo-dynamics, fluid mechanics, and chassis and transmission design. He also teaches internal combustion engine courses in applied design.

Mr. Harris joined GM in 1929 as an instructor in the Engineering Drawing Department at G.M.I. In 1940 he was made acting department head of the Product Engineering Department. He assumed his present position in 1946.

Michigan State University granted Mr. Harris the B.S.M.E. degree in 1929 and the M.E. degree in 1946. He is a member of the Society of Automotive Engineers and serves on various committees of this Society.



JOHN H. McLEOD, JR.,

co-contributor of the problem "Determine the Minimum Torque on an Automotive Engine Connecting Rod Bolt," and the solution appearing in this issue, is a project engineer at Cadillac Motor Car Division.

Mr. McLeod joined Cadillac in 1952 as a General Motors Institute co-op student. In 1957 he was granted the Bachelor of Mechanical Engineering degree from G.M.I. His G.M.I. Fifth Year Project Study Report was entitled "Advance Design Study of a Possible 390-Cubic Inch Engine."

Before assuming his present position in 1958, Mr. McLeod held the positions of laboratory technician and junior engineer. As a project engineer, Mr. McLeod is responsible for the development and testing of piston rings, crankshaft bearings, and connecting rods. His previous activities included engine power development work.

BERNARD J. RILEY,

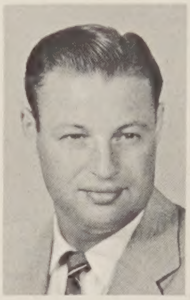
co-contributor of "A Radioisotopic Study of Leveling in Bright Nickel Electroplating Baths," is a research chemist in the Isotope Laboratory of the Physics Department, General Motors Research Laboratories. He is the radiochemist responsible for applying tracer techniques to Research and Divisional problems. and, presently, is continuing work on the application of radiotracer techniques to the study of leveling in electroplating baths.

Mr. Riley joined the Research Laboratories in 1955 as a research chemist. His work with GM has included the study of possible radiotracer techniques to investigate corrosion and the effect of impurities in plating baths. He also is on the staff of an isotope training program conducted for GM Divisional engineers by the Research Laboratories in conjunction with General Motors Institute. Before joining GM, Mr. Riley was employed by the Pittsburgh Plate Glass Company and the Special Weapons Command of the U. S. Air Force. He received the B.S. degree from St. Mary's College (Winona, Minnesota) in 1948, and the M.S. degree from the University of Detroit in 1950. He is a member of Delta Epsilon Sigma, honor society, the American Chemical Society, and the American Nuclear Society.

EDWARD C. SINTZ, co-contributor of the problem "Determine the Minimum Torque on an Automotive Engine Connecting Rod Bolt," and the solution appearing in this issue, is an assistant staff engineer at Cadillac Motor Car Division. His present responsibilities include directing engine design and developmental work.

Mr. Sintz joined Cadillac in 1928 as a General Motors Institute co-op student. He graduated from G.M.I. in 1931. A series of promotions led to his present position, which he assumed in 1950. His previous major projects have included piston development, valve gear problems, and fatigue problems.

Mr. Sintz is a member of the Society of Automotive Engineers. In 1951 he was granted the Bachelor of Industrial Engineering degree from General Motors Institute.

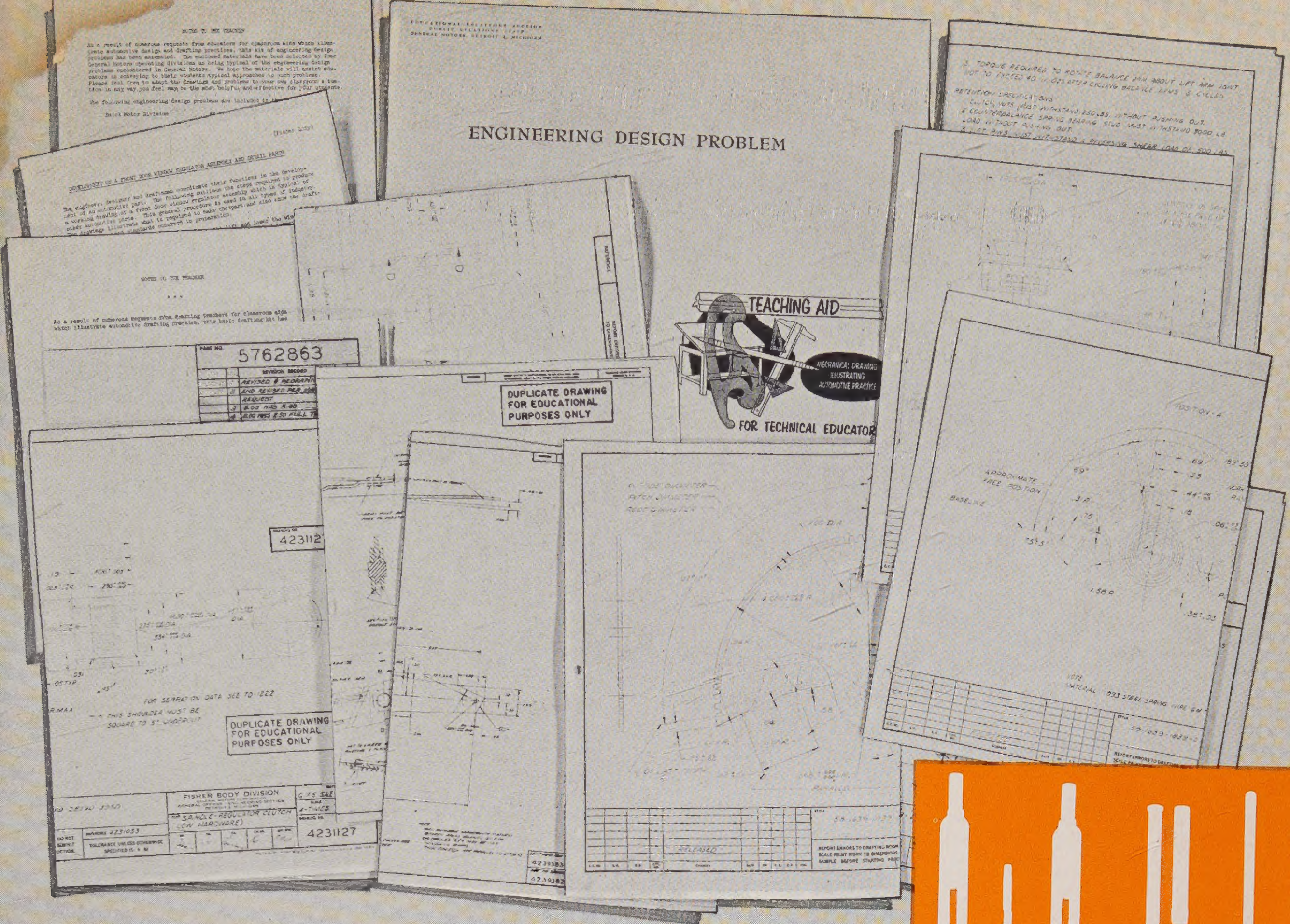


BLAIR THOMPSON, contributor of "Improving Product Design: Development of the Rotary Valve Steering Gear," is assistant chief engineer of the Saginaw Steering Gear Division, Saginaw, Michigan. In his present position he is responsible for the development and design of power steering gears for all applications.

Mr. Thompson joined GM in 1945 as a General Motors Institute cooperative student sponsored by Saginaw Steering Gear. He received the Bachelor of Industrial Engineering degree from G.M.I. in 1950, and was elected to membership in Alpha Tau Iota, engineering honor fraternity.

After graduation, Mr. Thompson continued with the Product Engineering Department at Saginaw Steering Gear. He served as junior designer, designer, project engineer, and senior project engineer before assuming his present duties in 1957. While in the Product Engineering Department, his projects included work in the applications of power steering, and the design of the Saginaw in-line power steering gear.

Mr. Thompson's technical affiliations include membership in the Society of Automotive Engineers and the Senior Industrial Club of Saginaw.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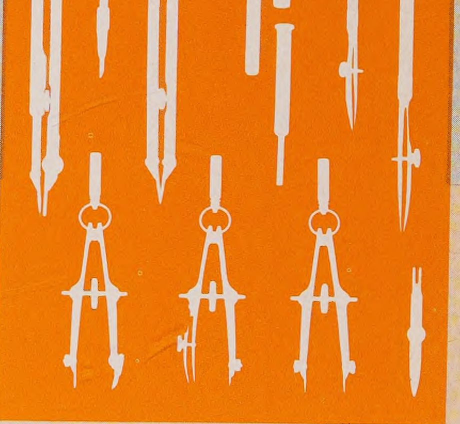

DESIGN ENGINEERING AND DRAFTING PROBLEMS AVAILABLE TO EDUCATORS

As a result of numerous requests from educators for teaching aids which illustrate automotive design and drafting practice, a kit consisting of four typical engineering design and drafting problems is now available. Material for the kit was developed by four GM Divisions.

The four problems include: the design of a torque ball, consisting of one photograph and eight drawings; the design of an instrument panel support, including a preliminary explanation and seven drawings; the development of a front door window regulator assembly, including an explanation of the outline followed to produce a working drawing of the regulator assembly, some typical regulator assembly drawing notes, and eight drawings; and the design of helical oil pump gears, consisting of mathematical computations and four drawings. All of the drawings in the kit are blue line ozalids.

Engineering educators interested in the design and drafting kit may write to the Educational Relations Section, GM Technical Center, P. O. Box 177, North End Station, Detroit 2, Michigan. A similar kit containing typical drawing reproductions illustrating current automotive drafting practice also is available to college and high school drafting teachers.

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